Fermilab

BP

…not British Petroleum

but “Big Proton” plan

V.Shiltsev

Content:

- How bad things are now at 240e9 protons per bunch
- How good things can be at a new WP with >360e9 protons/bunch
- The Plan

Luminosity Factors

$$L = \left(\frac{3\gamma f_0}{\pi\left(1+\varepsilon_{\bar{p}}/\varepsilon_p\right)} \right)\left(BN_{\bar{p}}\right)\left(\frac{H\left(\sigma_l/\beta^*\right)}{\beta^*} \right)\left(\frac{N_p}{\varepsilon_p} \right)$$

- Peak Luminosity: primary factors
  - Emittances : A/P ~12/18 now, ~6/18 RR only (+20%)
  - Number of antiprotons: max 1.7e12 now, >3.6e12 ***IF*** a) stacking rate is up from 15 to 45 mA/hr b) RR e-cooling works
  - Beta* at IP and bunchlength: H(x)/beta^*: now 0.64/0.35=1.8, will be 0.58/0.28=2.1 (+12%)
  - Last Factor → NEXT SLIDE
- Note: Integr.Lumi ~ PeakLumi^(0.6-0.7)

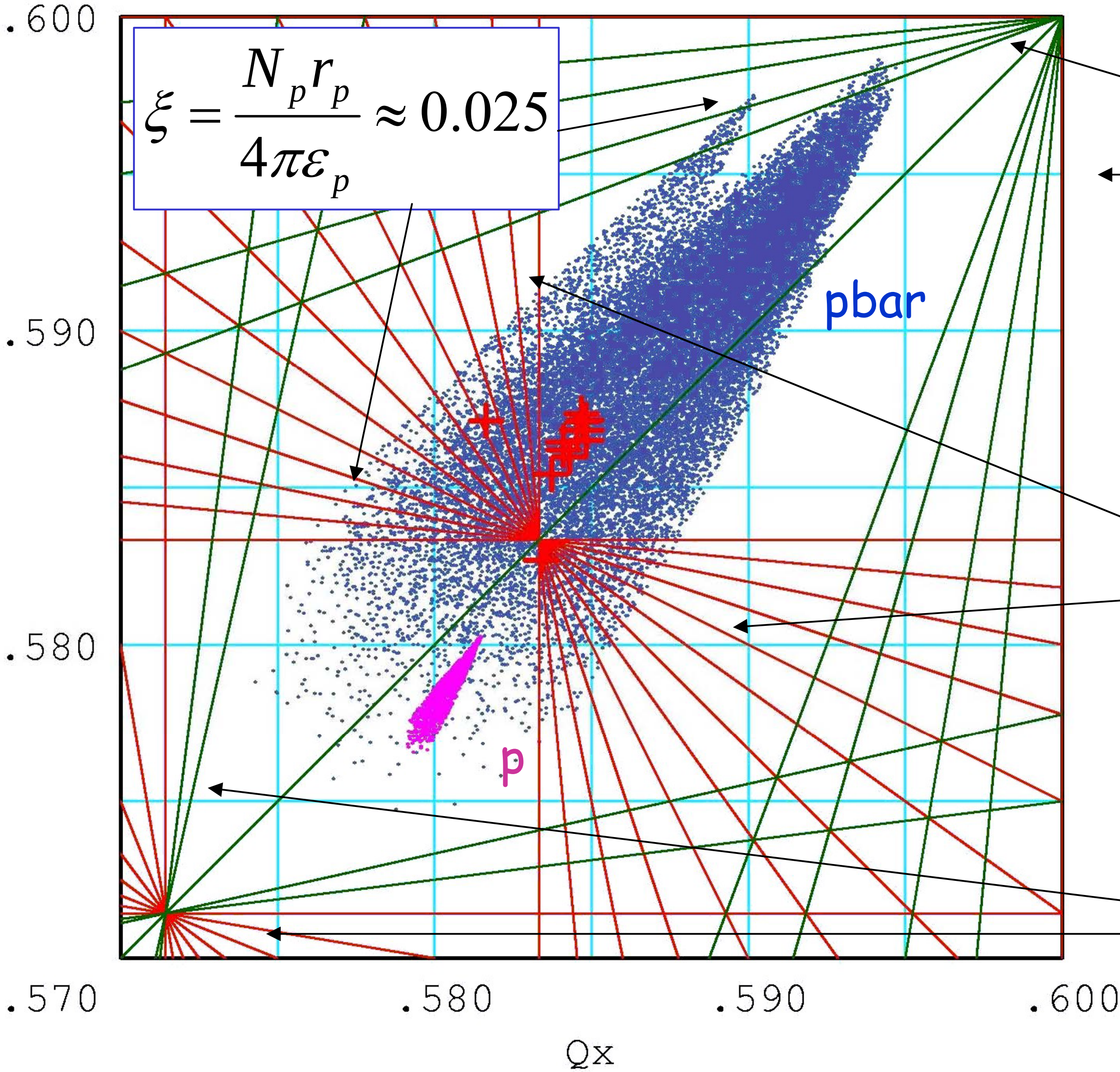
The Last Factor: Beam-Beam Tune Shifts

$$\xi = \frac{3N_p r_p}{2\pi\varepsilon_p^{95\%}} \times N_{IP}$$

ca 2004

Tevatron	a/p	+0.025/+0.005
RHIC	p/p	-0.014
HERA	p/e-	+0.0014/0.045
KEK-B	e+/e-	+0.113/0.072
PEP-II	e+/e-	+0.064/0.045
DAFNE	e+/e-	+0.055
LHC	p/p	-0.010

Situation at LB Now: Confined Beams



$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p} \approx 0.025$$

5th order resonances:

Q=3/5=0.600 –

EMITTANCE BLOWUP

12th order resonances:

Q=7/12=0.583 -

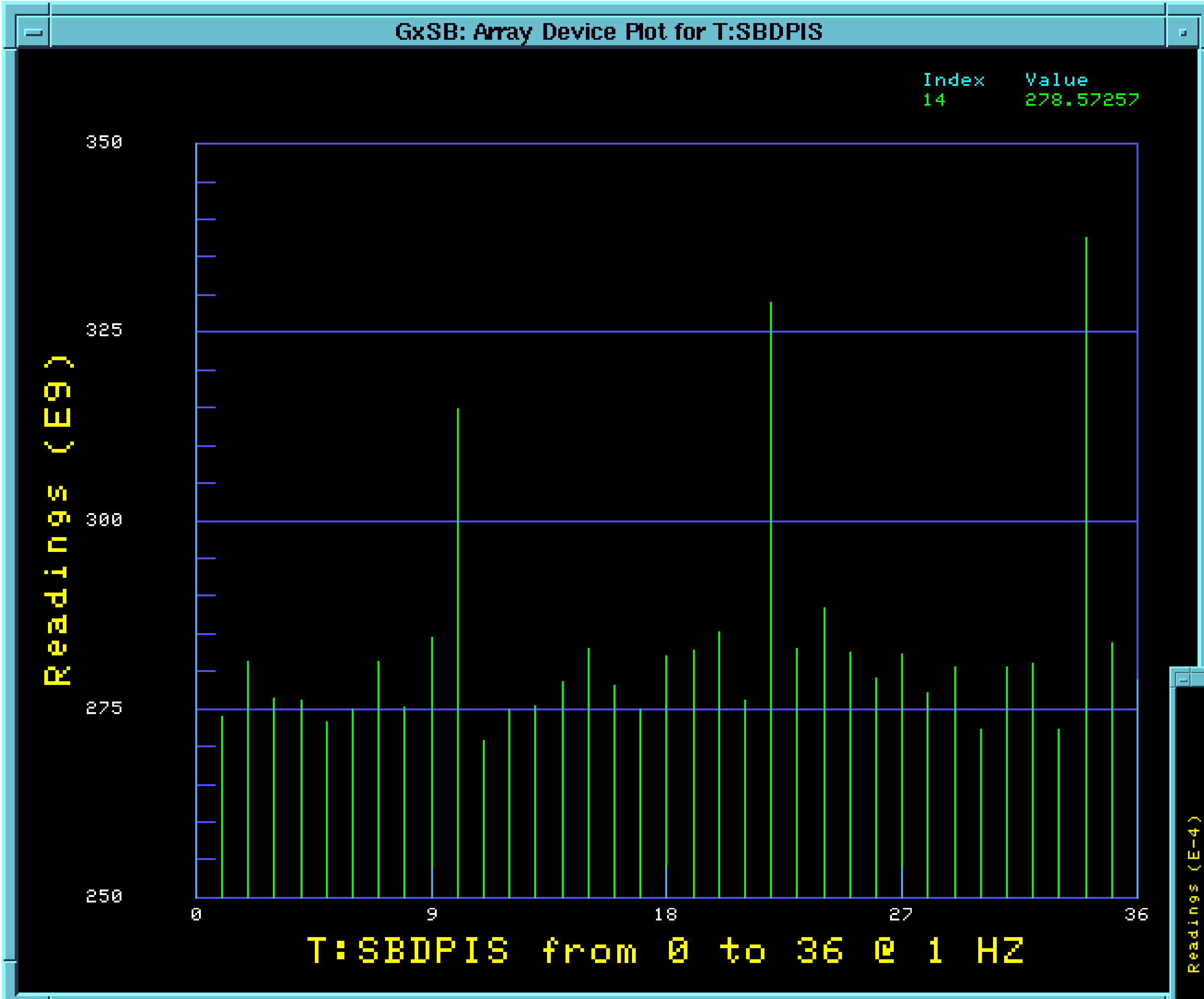
Bad lifetime

7th order resonances:

Q=4/7=0.571 -

HIGH LOSSES

Three Strong Proton Bunches: #4151



11 Booster turns/

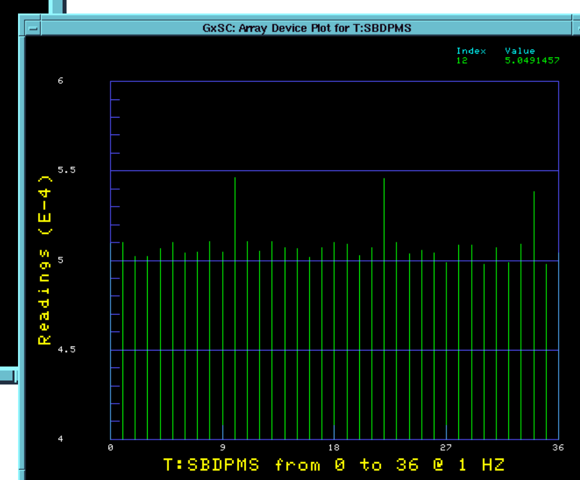
9 bunch coals MI

vs

9 Booster turns/

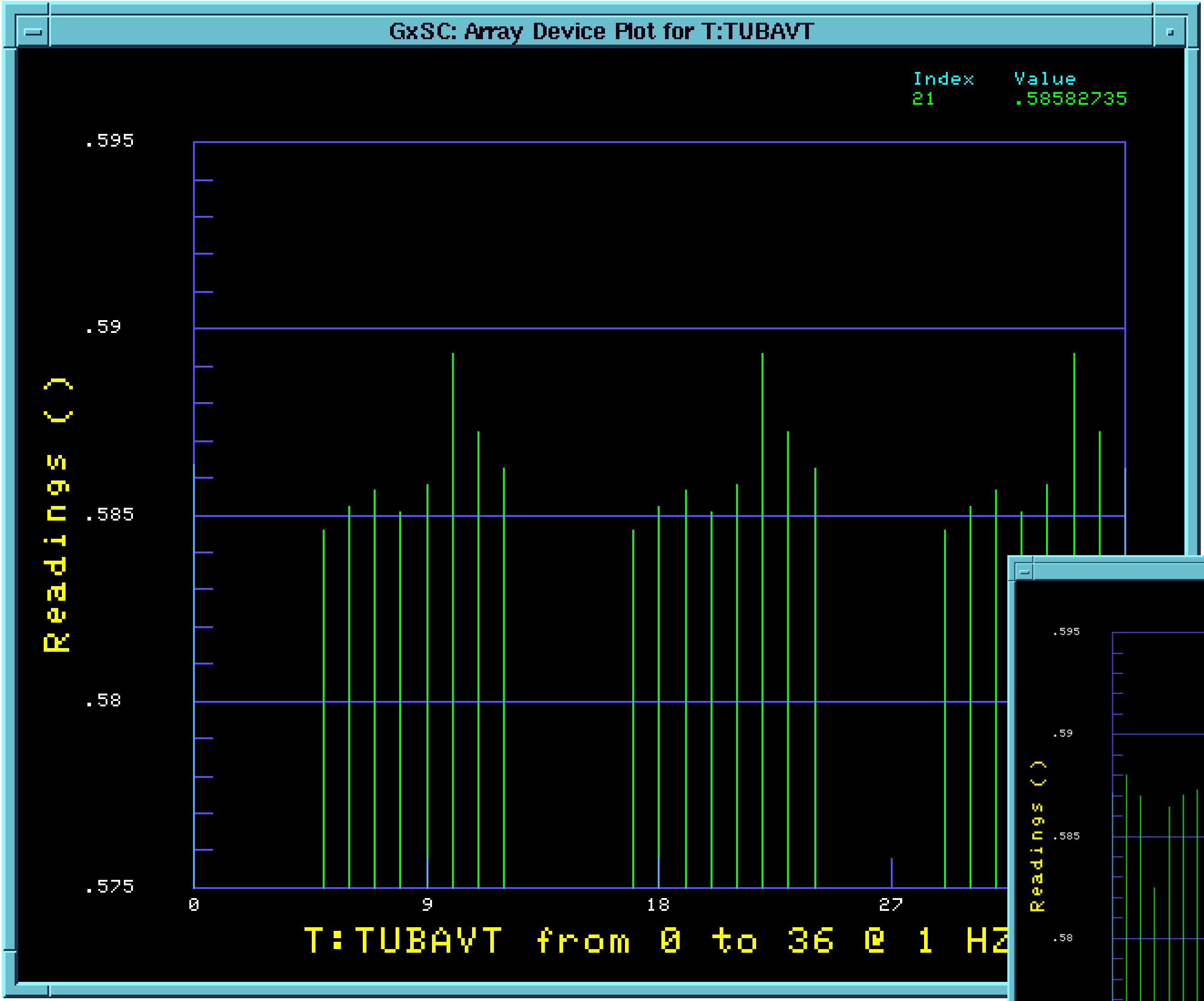
7 bunch coals MI

+20% in Emm_long



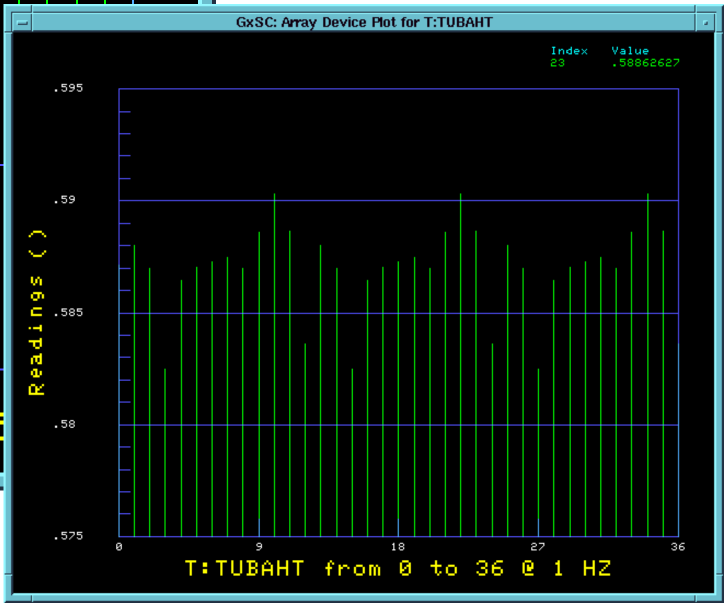
330e9 vs 280e9 at Inj; 280 vs 240 at LB

AntiProton Bunch Tunes @ LB: #4151

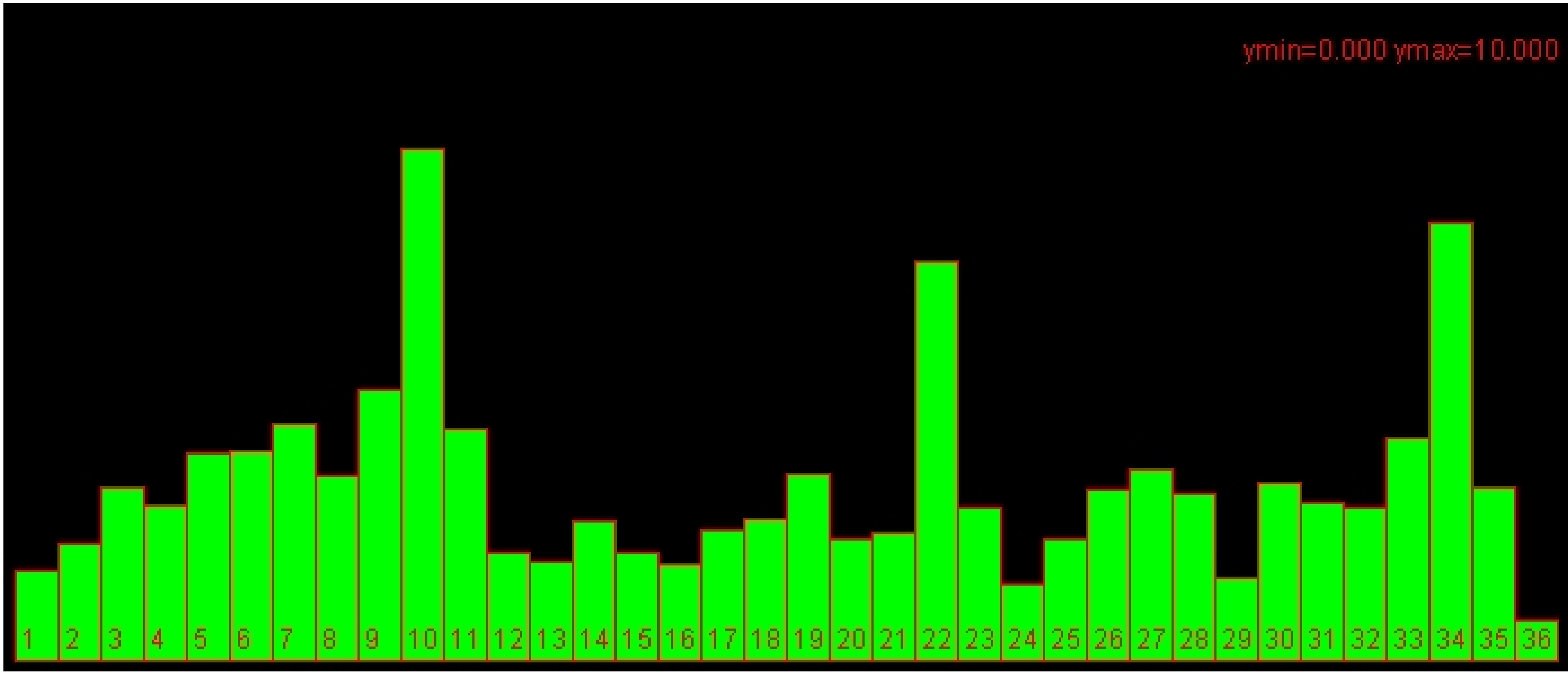


Vert

Hor



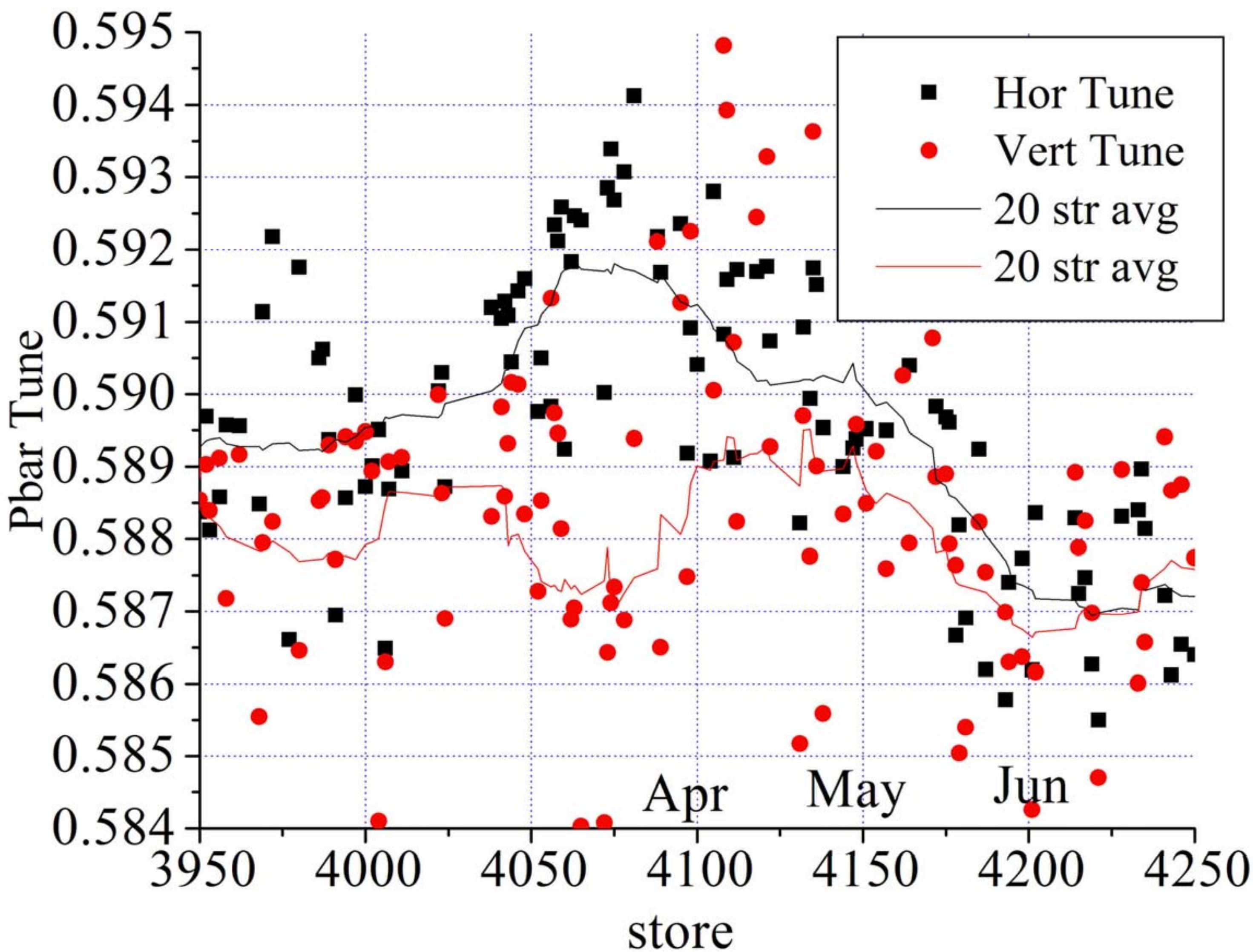
Anti-Proton Bunch Emittances: #4151



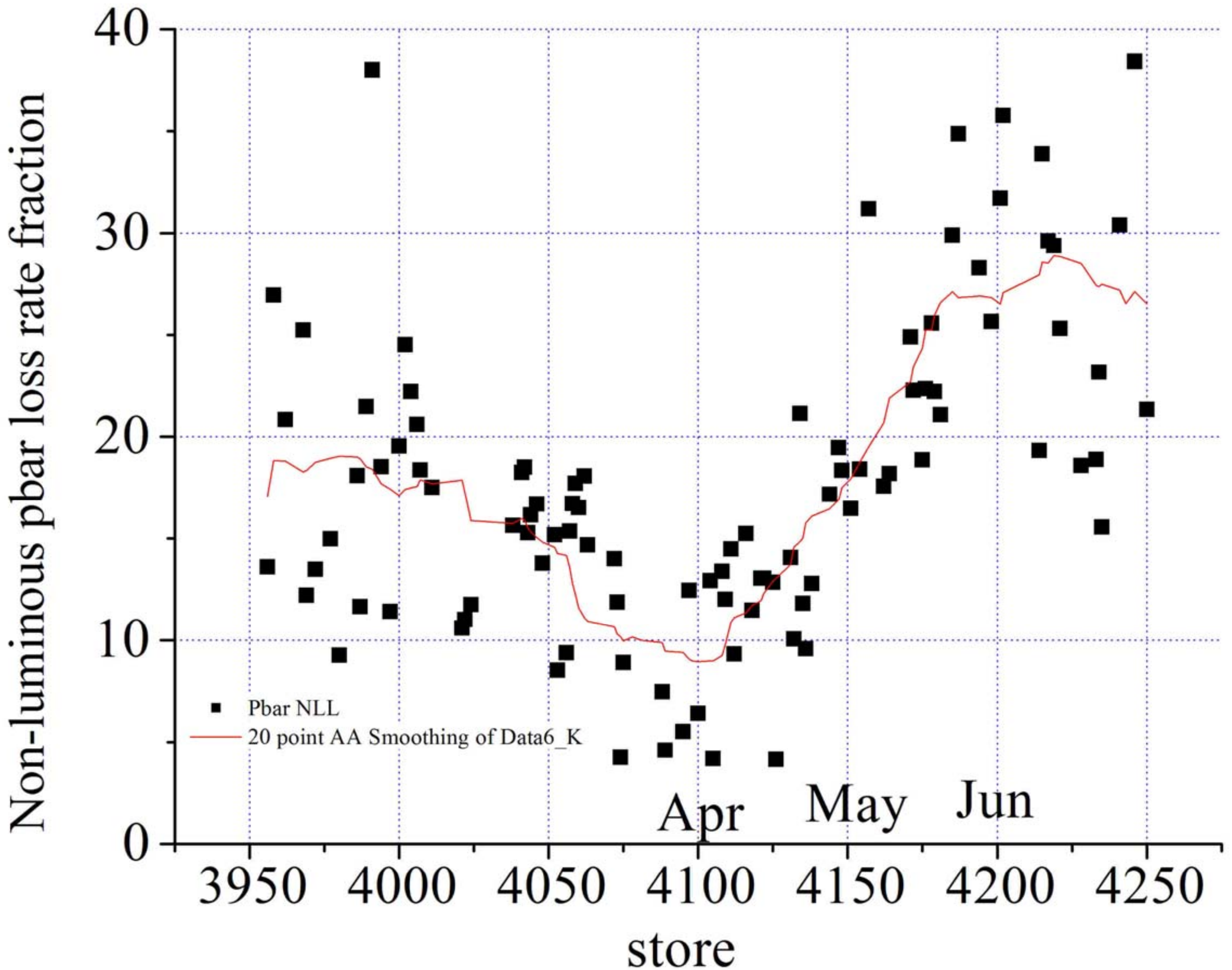
Pbar Vert Emittance Increase: "2 hrs in HEP" –"Start of HEP"

Net effect : ~+0.1% in integrated luminosity

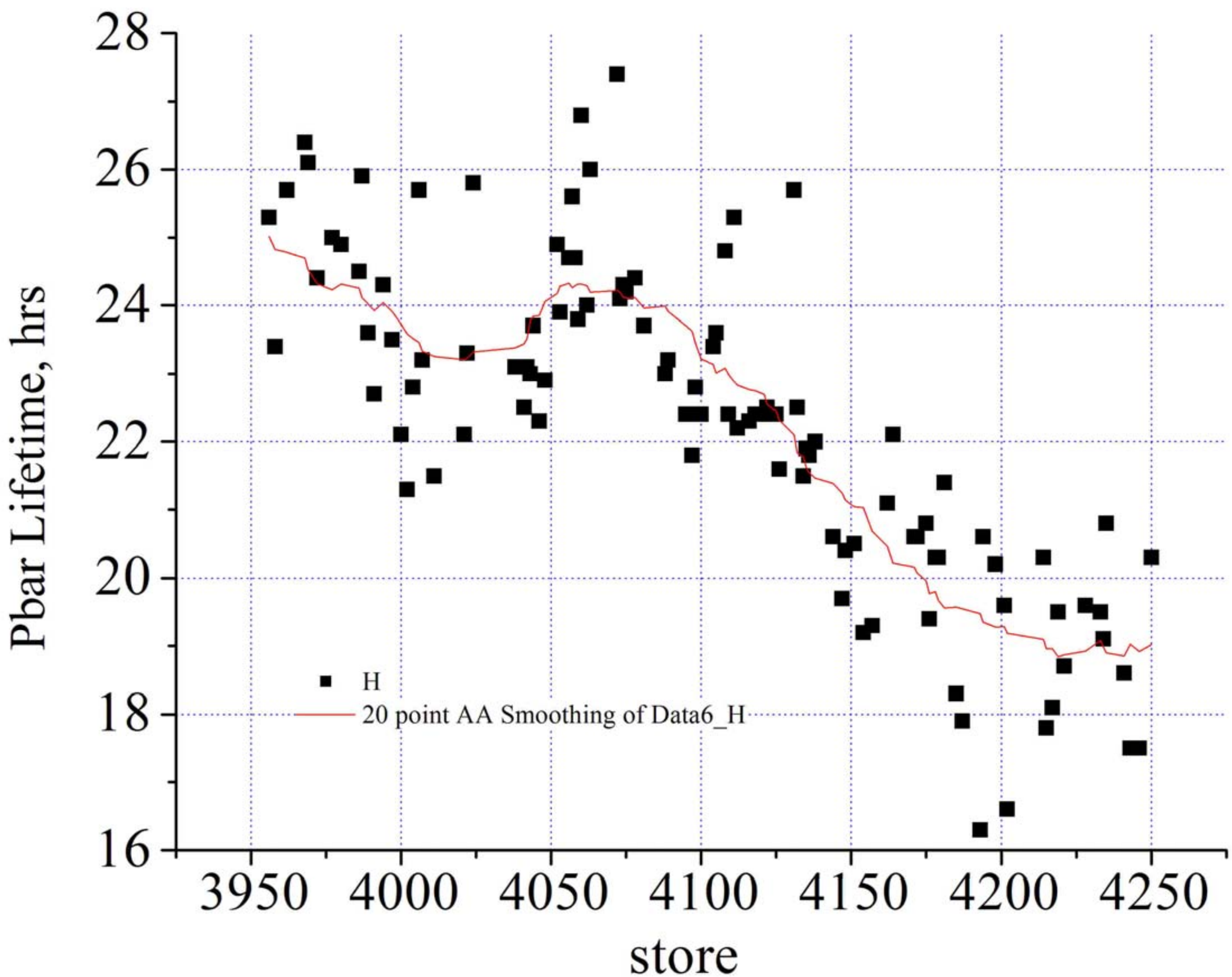
Pbar Non-Luminous Losses



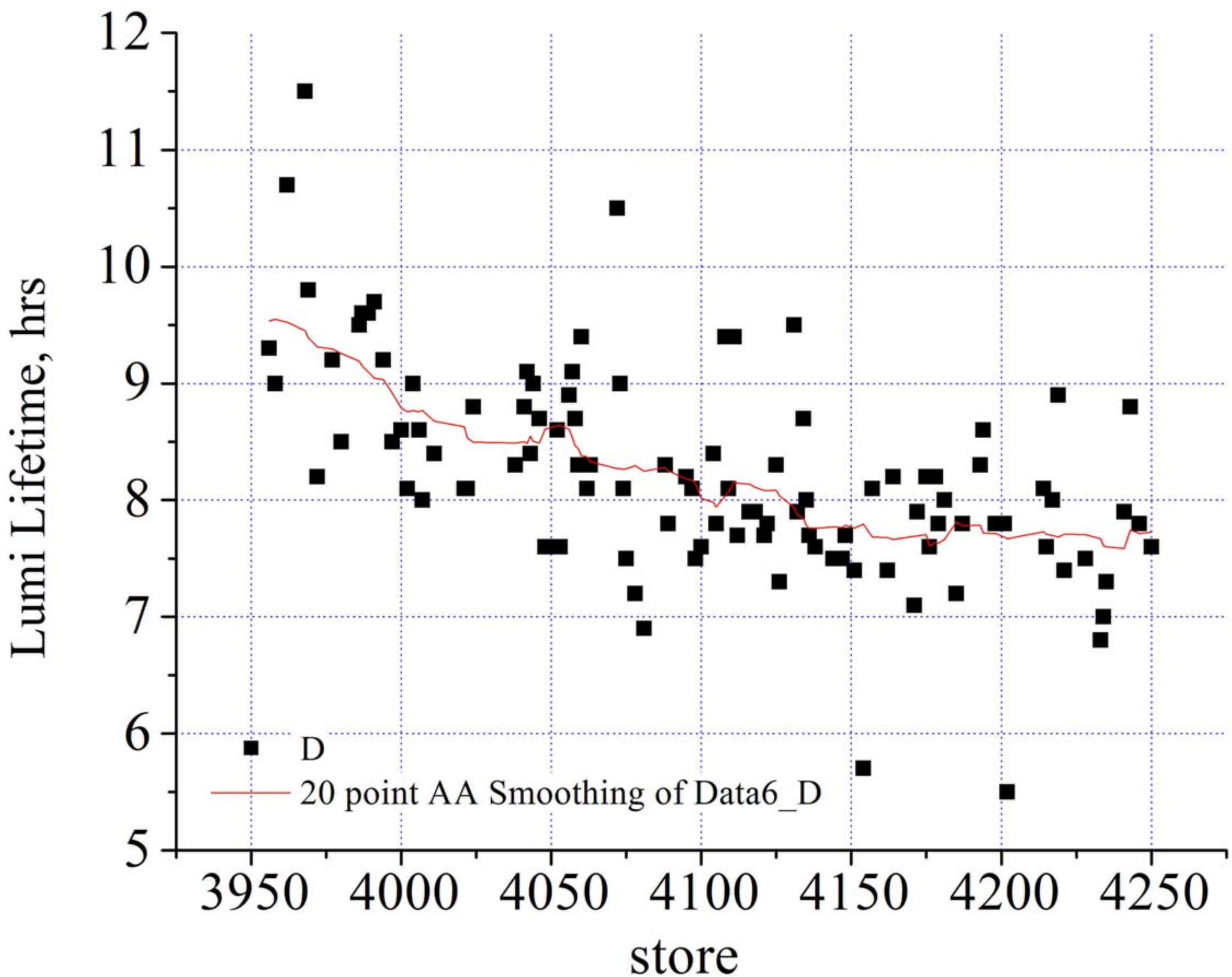
Pbar Non-Luminous Losses



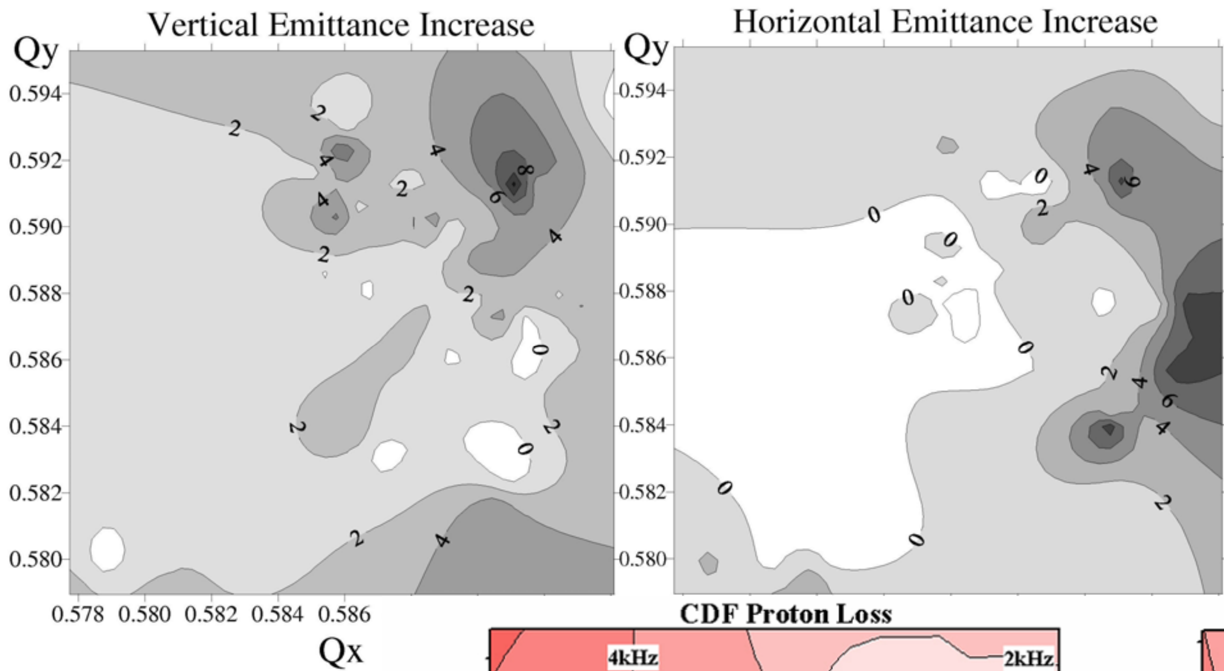
Pbar Lifetime since 05/2005

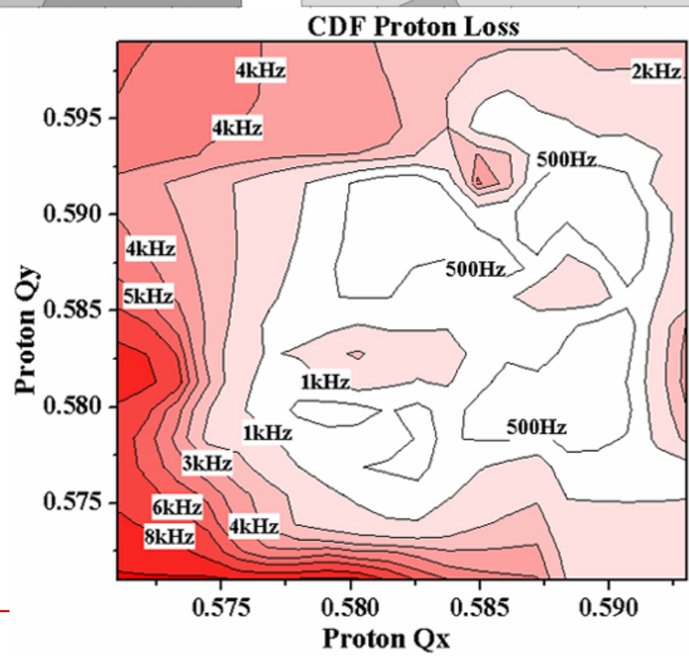


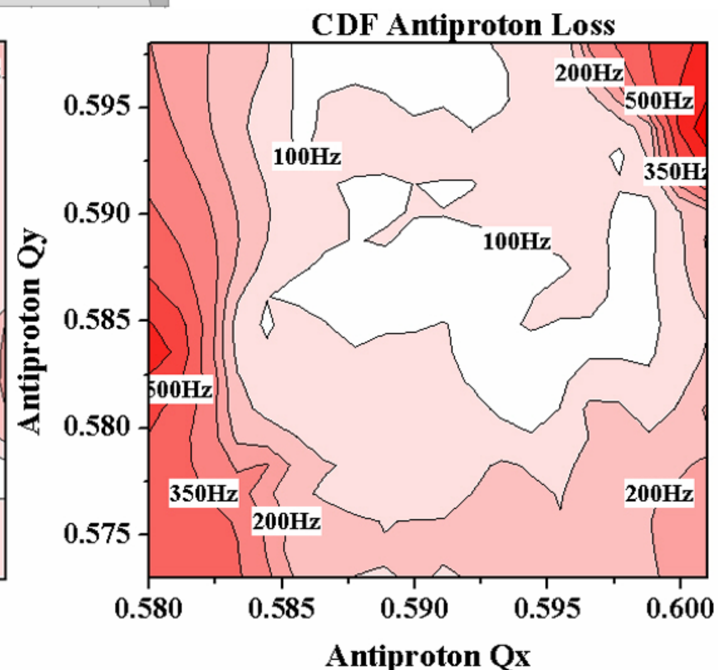
Luminosity Lifetime since 02/2005



The Choice: Lifetime or BlowUp







Big Proton Plan: Goals & Steps

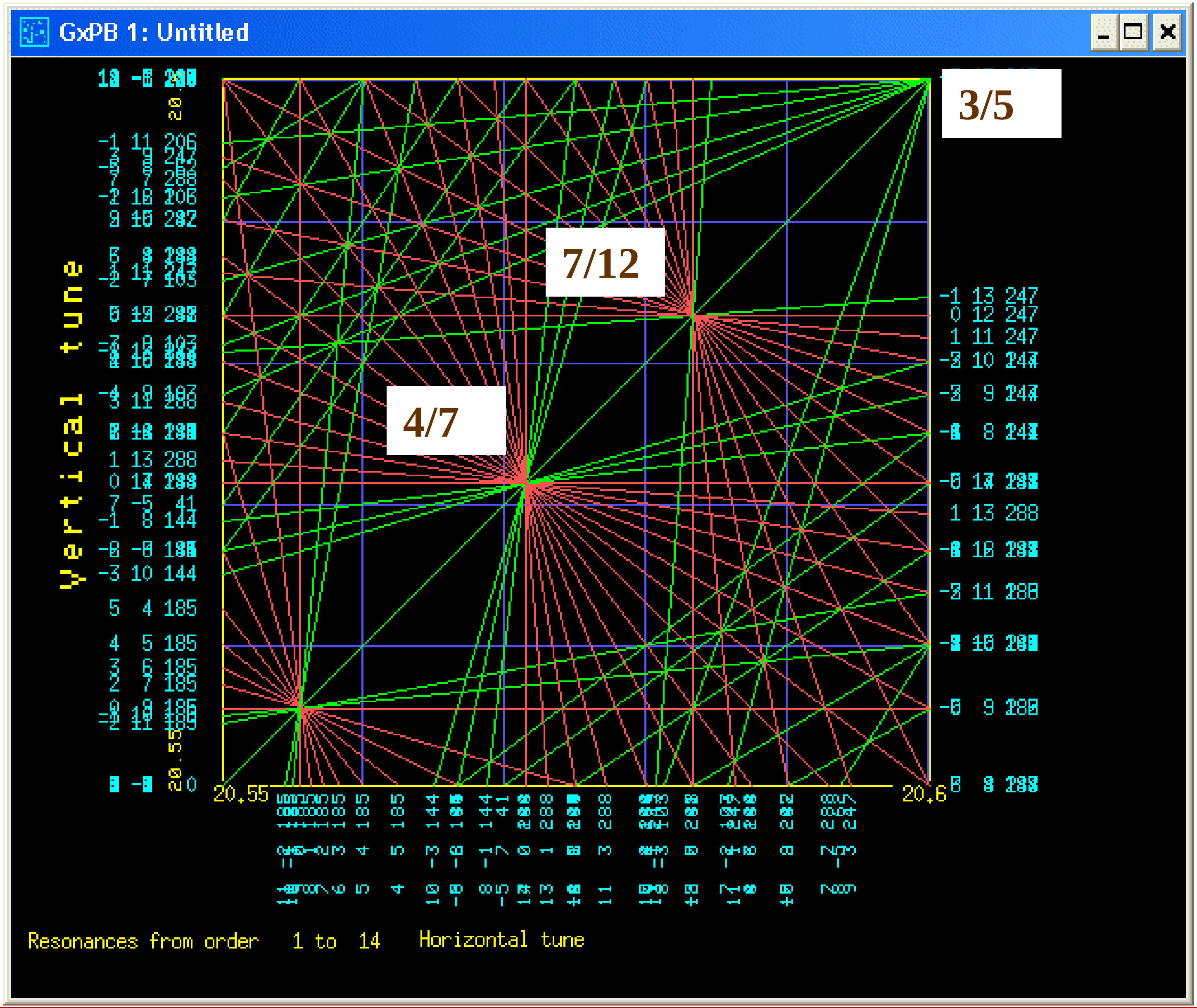
Goal: to increase luminosity above 210e30
by increasing proton intensity

3 stages with gain at each step, decision after each

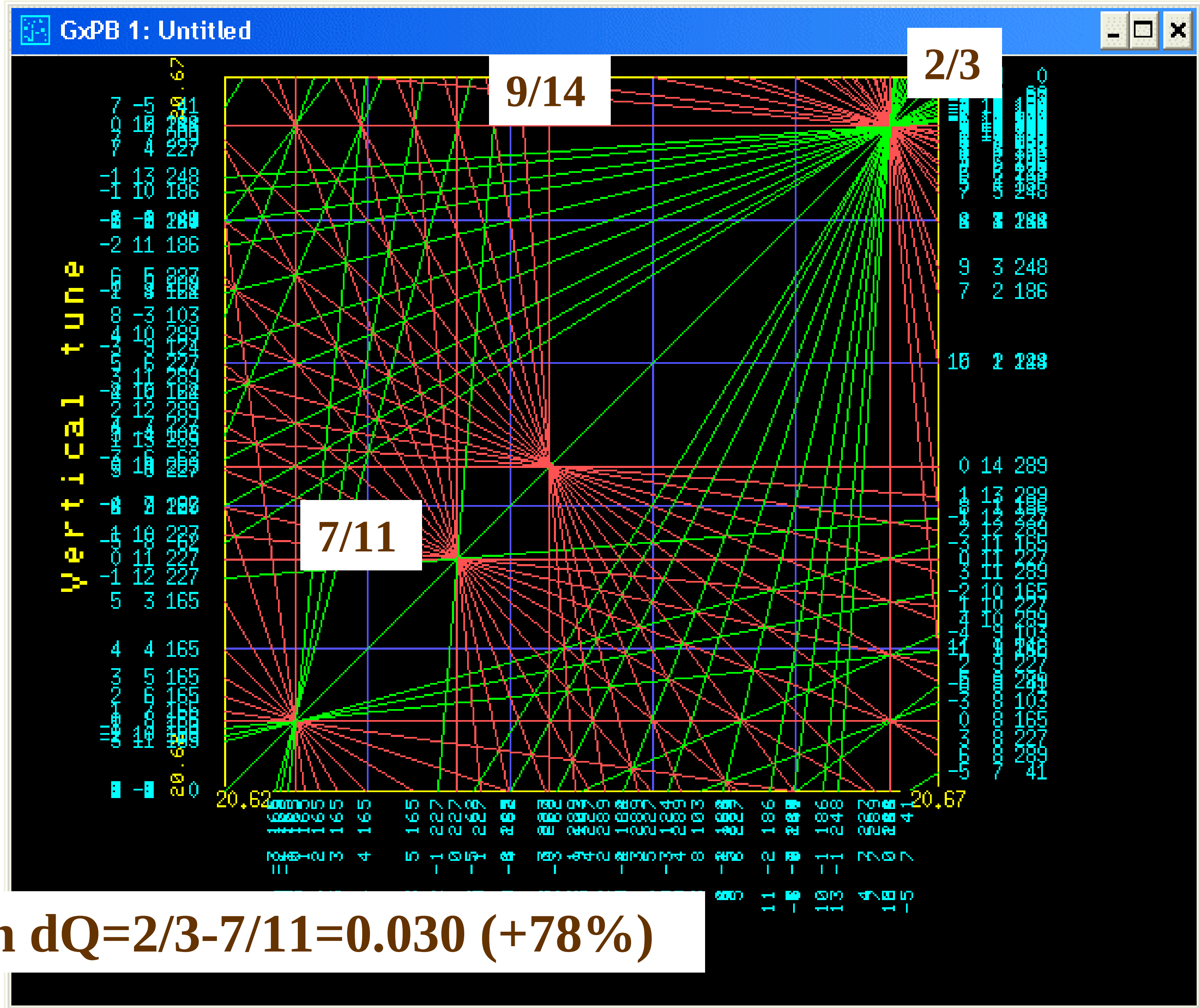
- Stage Zero:
  - change beta^* and establish optics x 1.10-1.15
- Stage One:
  - performs studies of 2/3 resonance
  - establish new WP below or above 2/3 x 1.0
- Stage Two:
  - increase Np from 240 to 330e9/bunch x 1.25-1.35
  - further increase to 380-400e9/bunch x 1.15-1.25
- Stage Three:
  - switch to 46x41 operation, increase Np x 1.05 - 1.10

TOTAL GAIN: x (1.5-2) in L_peak (>2.1e32), 1.3-1.6 in Int

Tune Space Now: 3/5-7/12=0.017

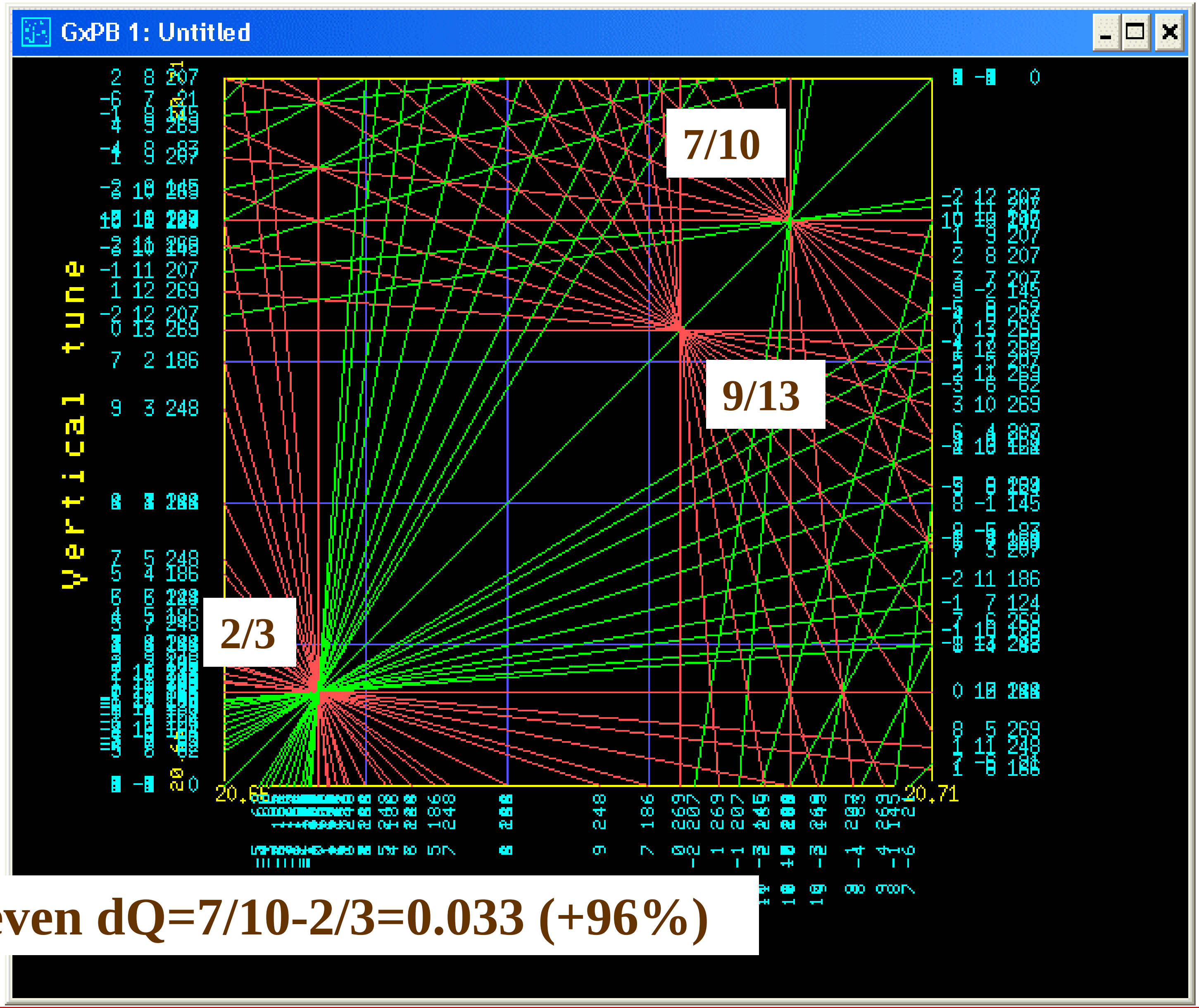


New WP#1: dQ=2/3-9/14=0.024 (+40%)



Or even dQ=2/3-7/11=0.030 (+78%)

New WP#2: dQ=9/13-2/3=0.026 (+50%)

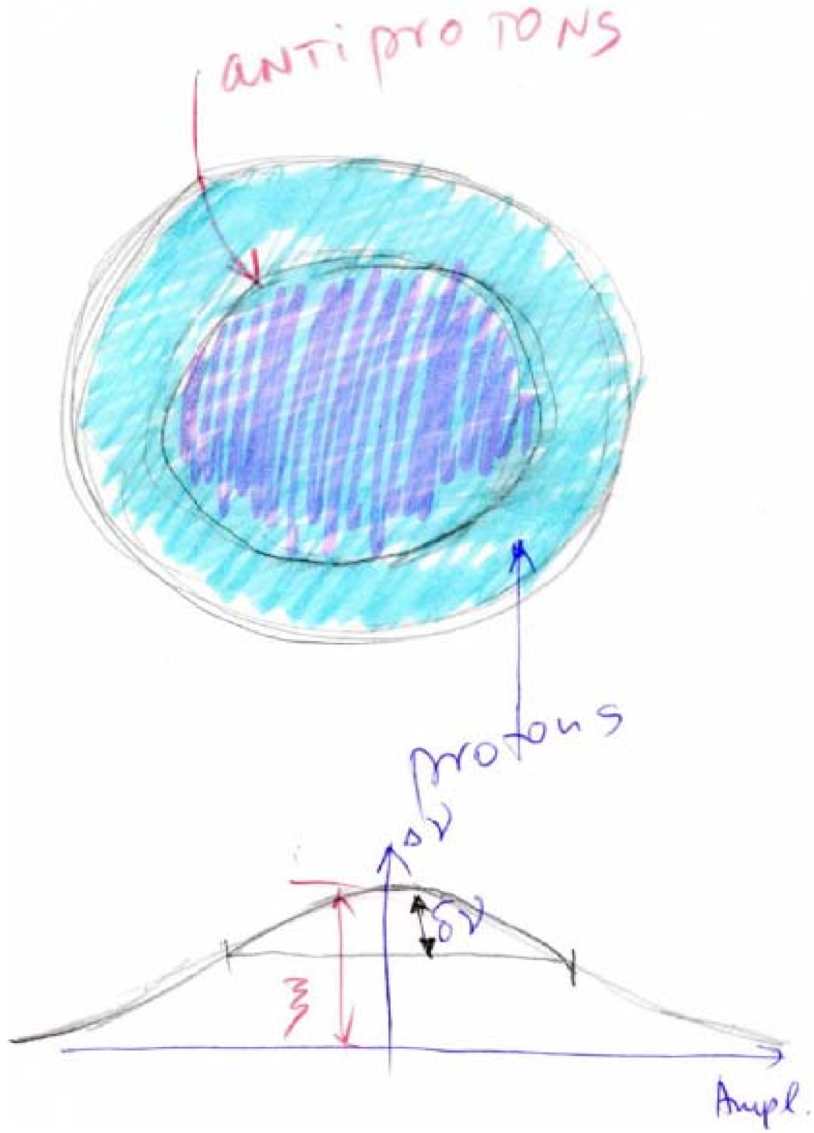


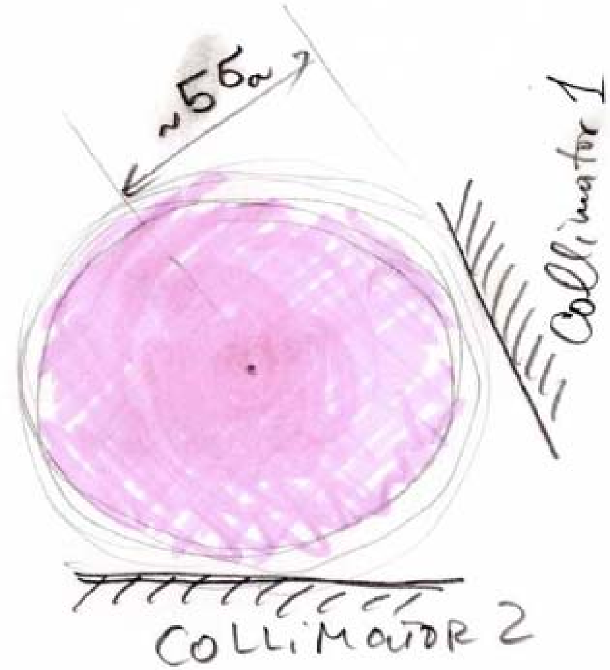
Or even dQ=7/10-2/3=0.033 (+96%)

Which of Two WPs Is Better?

- WP#2 offers bigger space
- WP#1 has the same placement of resonances as now: strong on top (core), weak on bottom (halo)
- WP#1 has 14th order below which may be tolerable → then 11th order offers larger space
- Same may be true for WP#2 (13th →10%) – for core particles
- IMPORTANT NOTES:
  - with 5 pi pbars from RR (only) and 15pi protons, tune spread upto 5-6 sigma particles will be less than ksi by ~ 20-30% (→ possibility to increase Np)
  - chromatic tune spread becomes important for the Np increase as it reduces the tune space → use of octupoles or/and dampers to drop Q' to 0 may be essential for the plan

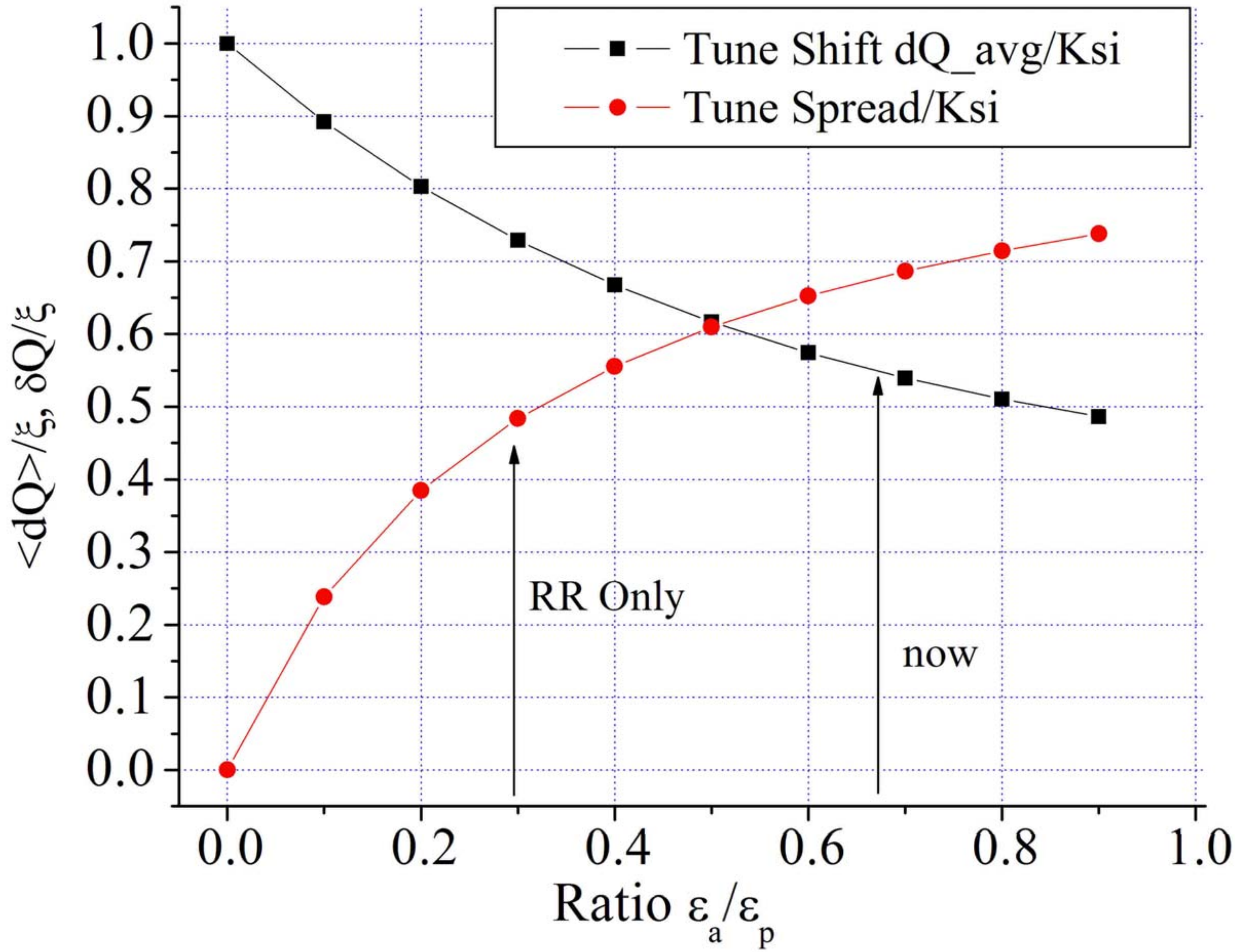
Two Effects: Larger Protons & Collimators



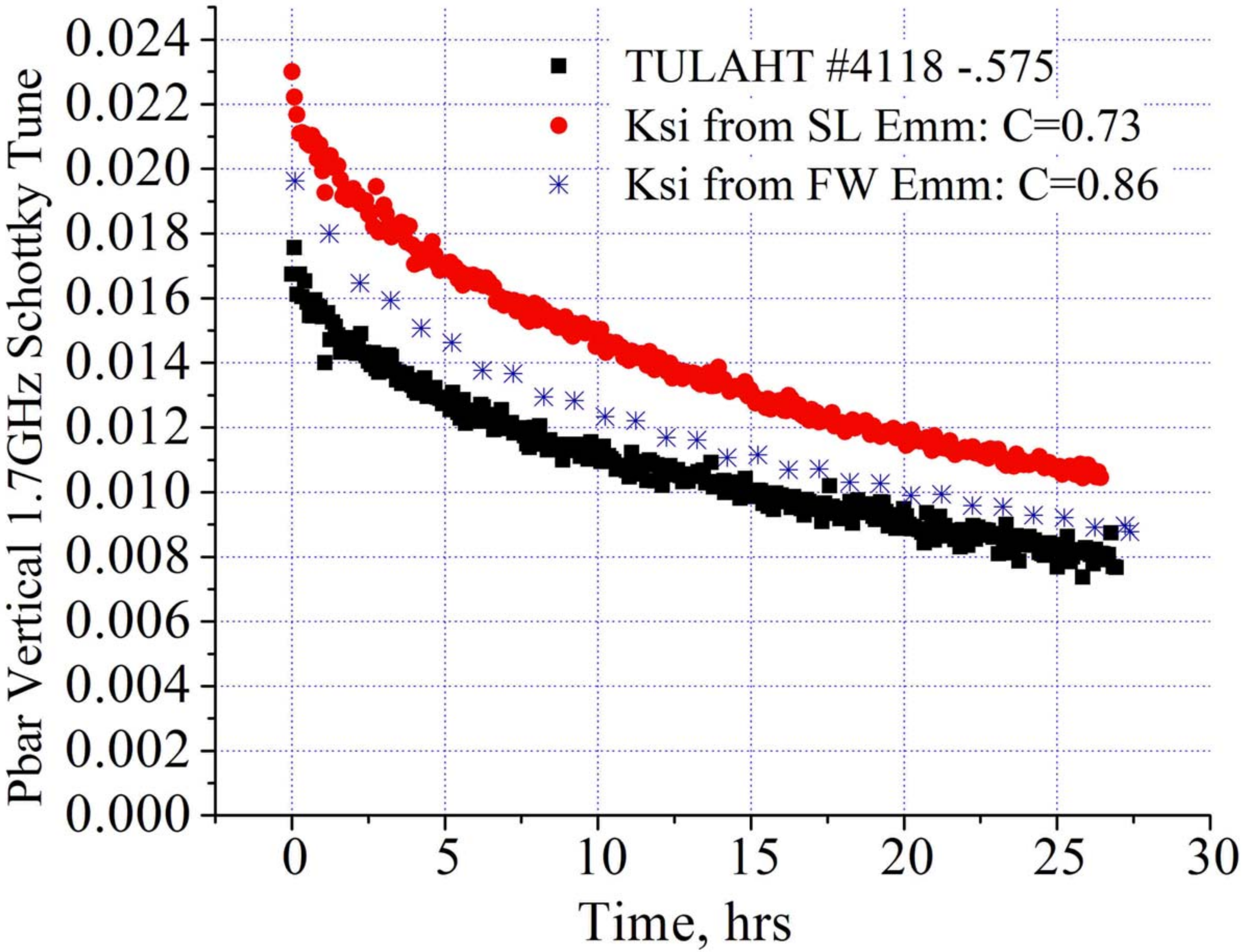


$$\Delta Q_{x,y}(I_x, I_y) = \frac{\xi}{1 + \frac{I_{x,y}}{2\varepsilon_p} + \frac{I_{y,x}}{4\varepsilon_p}}$$

Tune Spread and Tune Shift



Tune Drift from: Schottky, SL, FWs



Tune Space Summary

	WP#0	WP#1		WP#2	
Avail dQ	0.017	0.024		0.026	
		0.030 ?		0.033 ?	
ξmax	0.025	0.038		0.038	
Res.width	0.001	0.003 ?		0.003 ?	
		RR	Mix	RR	Mix
dQbb spread	0.018	0.019	0.025	0.019	0.025
dQ=Q'dP/P	0.002	0.002		0.002	
Total HO Spread	0.021	0.024	0.032	0.024	0.032

Stage 0: Beta* Reduction

- To take place in July-Sep'05
- New BPMs are essential for precise optics adjustment - commissioned, OK
- Beta* to be reduced from 35cm to 28 cm
  - due to hourglass effect, gain is SQRT(1/beta) ~ 10-15%
  - head-on beam-beam resonant driving terms, helix might change will change, too → need observations and to gain experience
- Resulted lattice and helix will be references for future operation after the change of working point

Stage 1: Change WP

- First, perform studies to evaluate new WP:
  - determine stopband width of 2/3 resonance wrt 3/5 at 150 GeV, may be at LB (1-2 shifts) – w/o pbars
  - compare emittance growth rates at 150 GeV at <3/5 and <2/3 (1 shift)
  - check stability of highest possible bunch intensity at 150 and 980 (1x0, 36x0) – to confirm that either octupoles or dampers can handle what MI can provide now (320-340e9 at 150 GeV) (1-2 shifts)
  - Commission new feeddown tune correction schemes (0.5-1 shift)
- Then, change the tunes all the way from 150 to LB
  - on C.O and helices
  - tune and coupling and chromaticity adjustments
  - parsing the squeeze
  - altogether ~4-6 shifts
  - operation @ new WP with present N_p, adjust knobs (~1-2 mos)
  - at the end – may gain 5-10% in Integrated luminosity (better τ)
- When? – Sep'05-Jan'06; no hit on luminosity integral

Stage 2: Increase N_p/bunch

- First, upto what MI can provide now (340e9?):
  - increase N_p in 1-2-3 steps; adjust Tevatron parameters in operation
  - commission octupoles or dampers on ramp if reliability or losses will be intolerable; same at LB
  - perform studies in MI to optimize long and transverse emittances, satellites at given intensities
  - optimize DC beam cleaning by TELs at new WP and collimation efficiencies (may be – TEL or/and collimators at 150 and on ramp)
  - all that may take some 3-6 mos
- If feasible, switch to superbunches in MI:
  - preceded by 20-bunch coalescing studies (C.Bhat) (8 x 2 hrs)
  - goal intensities 380e9/bunch, <2% satellites, long emittance <4eVs (may gain upto 5% in H(x), ~same transverse emittances
  - may take 1-3 mos of studies in parallel to collider operation
- Goal: 330e9 by May'06; 380e9 by Nov'06

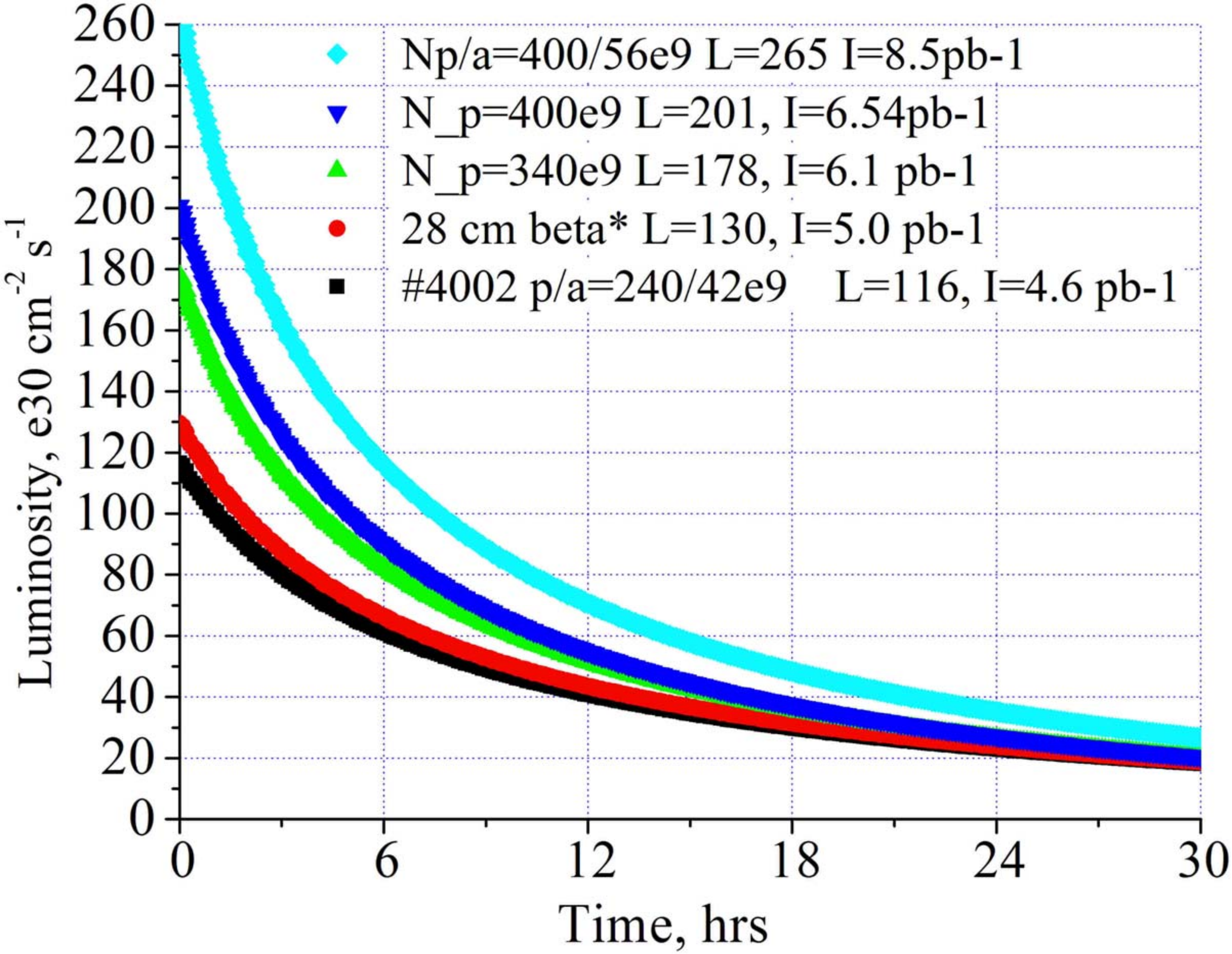
In parallel to Stages 1 and 2 (07/05-04/06)

- Perform following analysis/simulations:
  - estimate stopband width with beam-beam OFF/ON
  - evaluate difference in long-range interaction effects at new WP compared to present one : at 150 and LB
  - decide which WP is better : above or below 2/3
  - SB resonances with smaller beta* and new WP
  - consider the changes in the lattice finctions
  - evaluate relative danger of 9/14 vs 7/12 resonances
  - scallops near 2/3 vs near 3/5
  - will helix size matter at new WP? Will dependence be different from 1/helix^3
  - effect of octupoles at new WP

Stage 3 (Final) : 46x41 operation

- Switch to operation with (17+17+12) proton x (12+12+17) pbar bunches in the Tevatron:
  - same proton bunch intensity; just one abort gap; 396ns spacing
  - proportionally 15% lower pbar bunch intensity
  - the scheme will eliminate PACMAN bunches → more tune space, +10% in Np possible
  - # of interactions per crossing will be 15% lower (CDF and D0 will like that)
- Will require beam studies for:
  - injection logistics and scenario
  - RR studies to inject 17 bunches build time
  - evaluation of effects of 9 coggings at 150 GeV
  - possibility and necessity of TELs for tune compensation for 5 extra proton bunches
  - importance of 35RFC gaps for DC cleaning
  - total of ~(4-6) shifts
- Goal: 46x41 by Dec'06-Feb'07

Luminsity Evolution: Stage 0,1,2,3



Questions raised at the Tev Dept Mtg 06/17

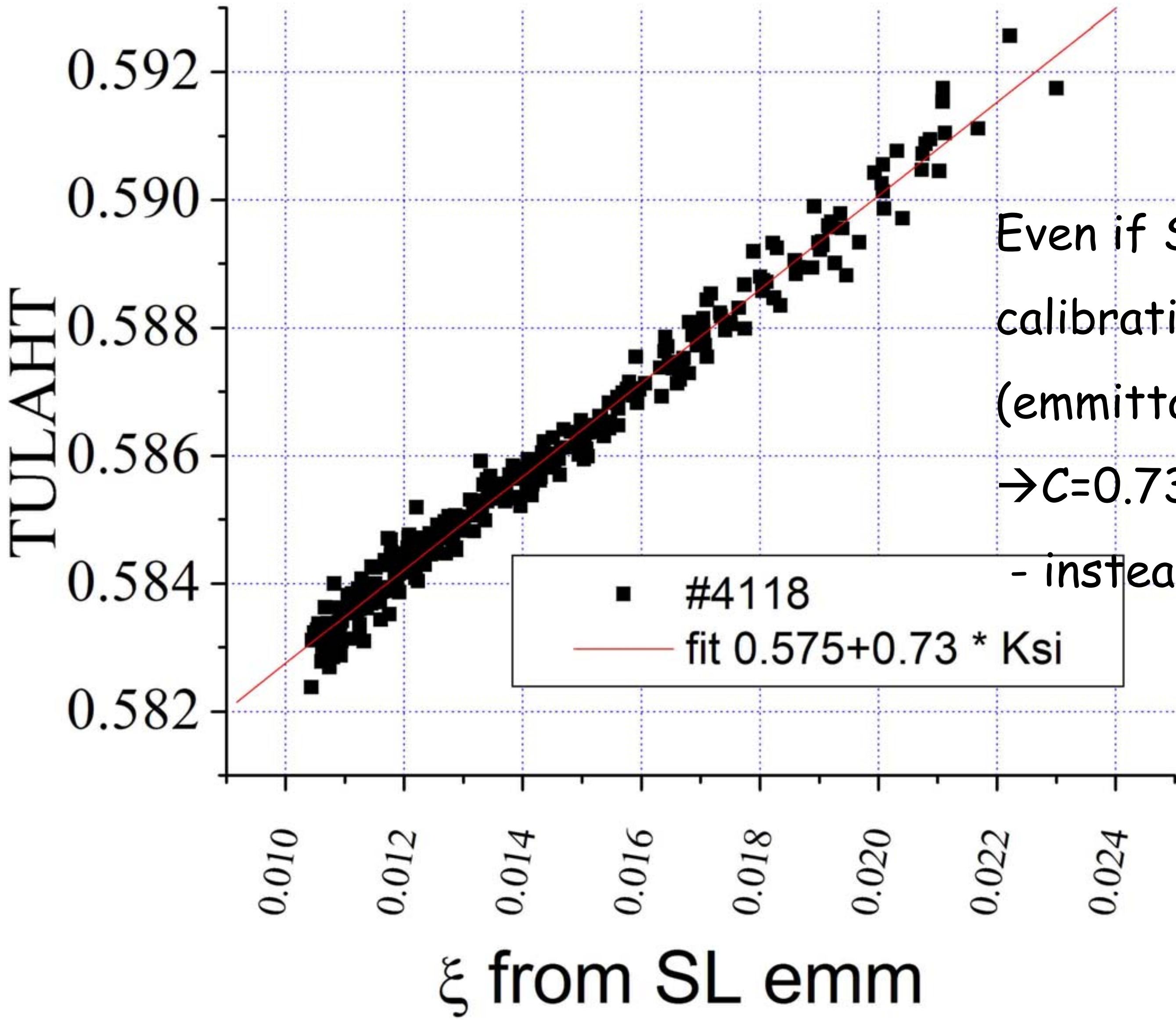
- will beam loading compensation be needed
- will transformation to a new WP affect feeddown circuits? Efficiency of scraping? Separator settings and Helix? Phase advance for dampers?
- we may want consider using sextupole correction circuits for compensation of 2/3 resonance
- will A0 abort handle that many protons?
- motivation for a current WP should be explored

Summary:

- New WP near 2/3 resonance should be much better than the current one <3/5
- It should allow to operate with ~360e9 protons/bunch thus ~1.5 x luminosity
  - some 30-35% in lumi integral/week
  - even with current Np~240 lifetime and losses should go down and give some 10% gain in integrated luminosity
- Even higher intensities >(400-420)e30 (and proportionally higher luminsities) are possible:
  - If we switch to 100% RR pbars with smaller emittances (less spread)
  - Strength of 2/3 resonance reduced by corrector magnets
  - Octupoles at LB used to reduce chromaticity and free WP area

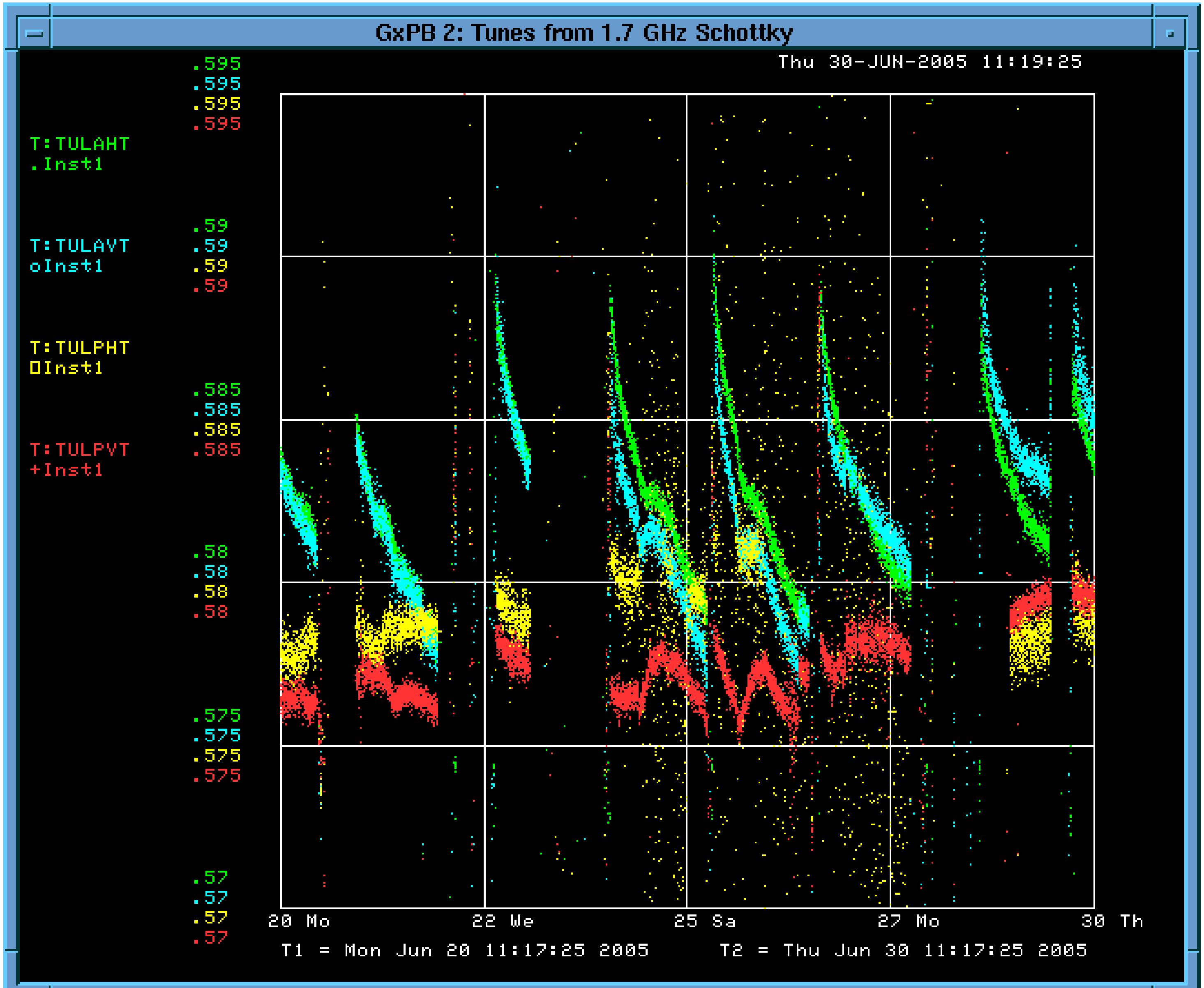
Back Up Slides :

Tune Shift: Schottky vs SL

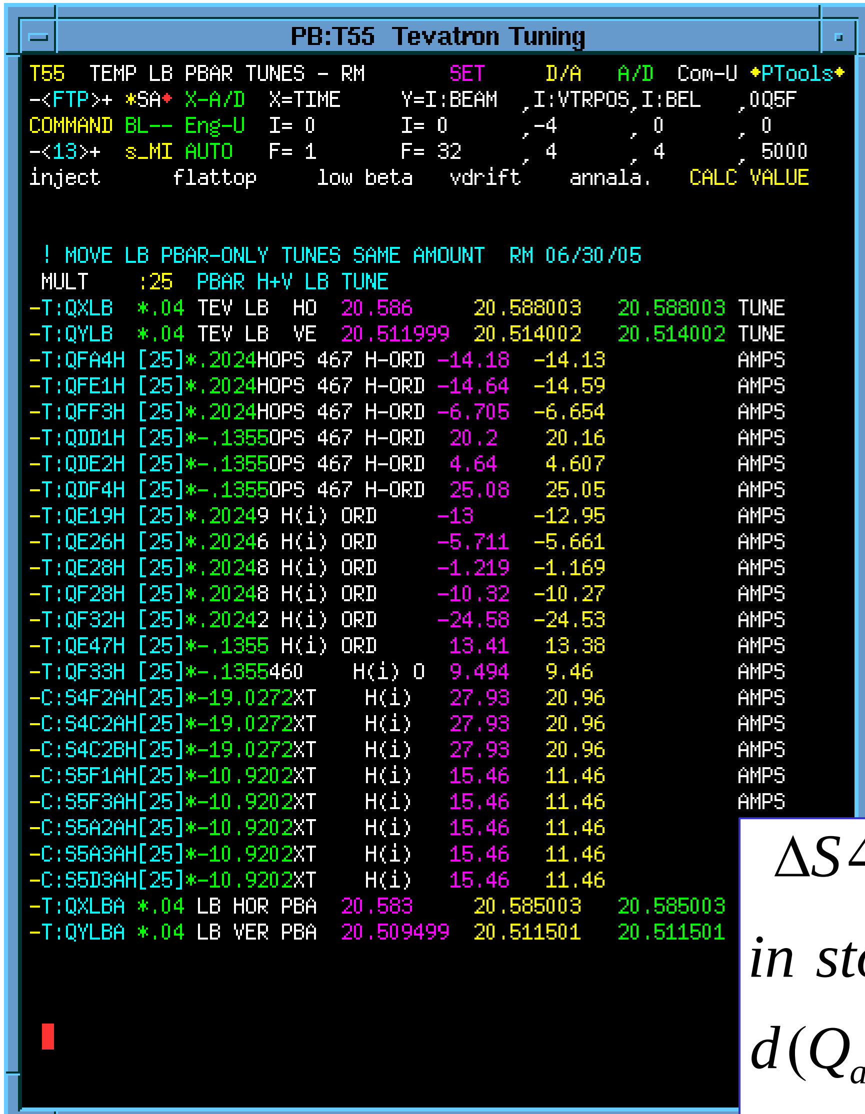


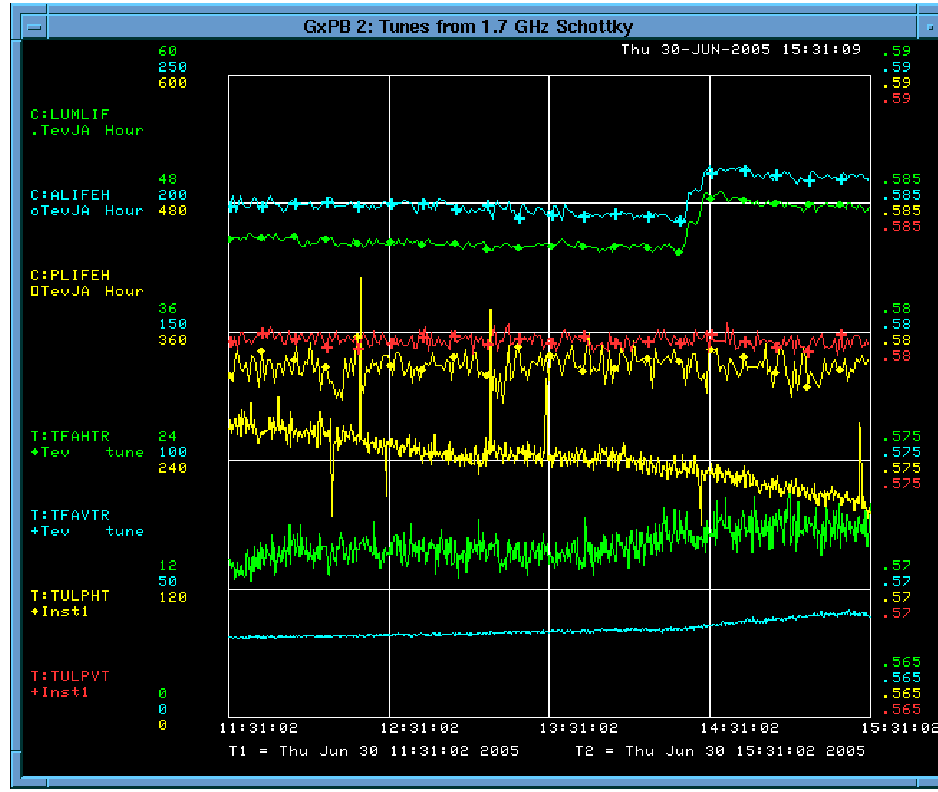
Even if SL Emm calibration 0.91 off (emmittances smaller) →C=0.73*0.91=0.66 - instead of 0.55

Tune Drift : from 1.7 GHz Schottky



Pbar Tunes: Bare Tunes





$$\Delta S4F2AH = 7A \rightarrow d(Q_a - Q_p) = +0.002$$

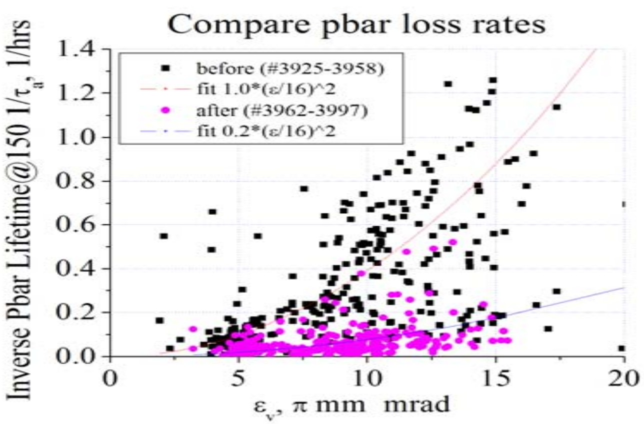
$$in\ store\ \Delta S4F2AH = 21A \rightarrow$$

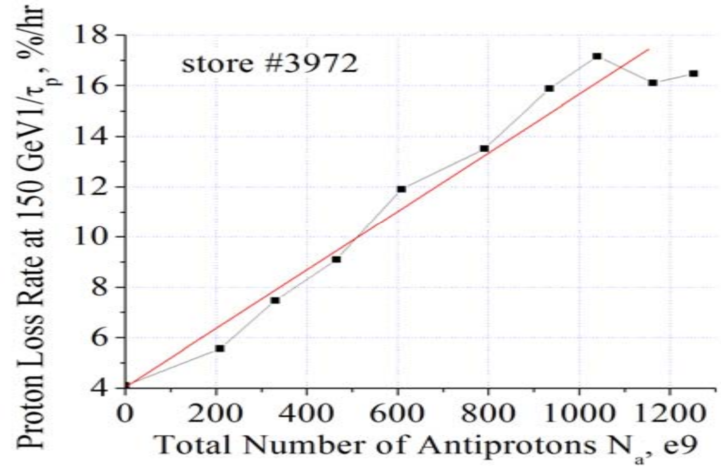
$$d(Q_a - Q_p)_{bare} = +0.006$$

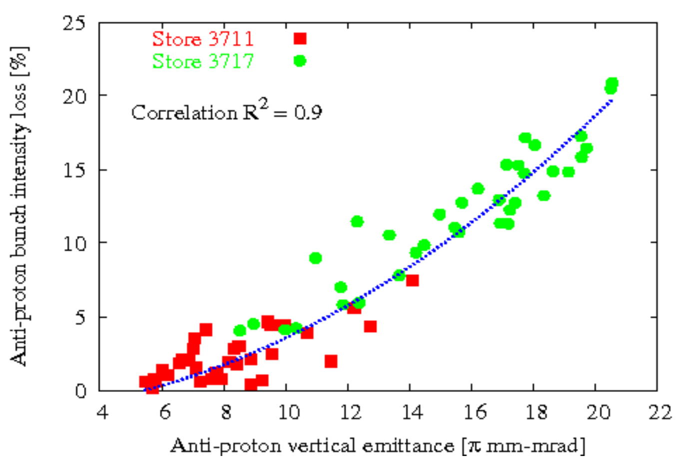
$$Q_{p\,bare} = +0.578 \rightarrow Q_{a\,bare} = +0.572$$

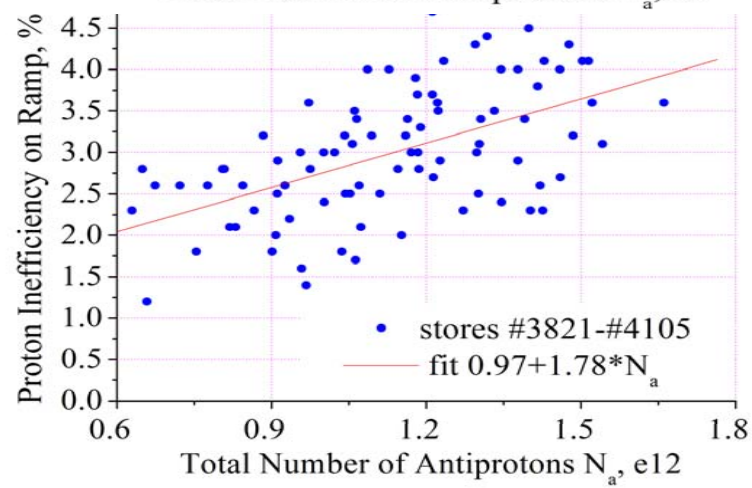
Beam Losses Before Collisions

$$\frac{dN_{a,p}}{N_{a,p}} \propto \sqrt{t}\cdot \varepsilon^2_{a,p} N_{p,a} Q'^2{}_{a,p} \times F_1\left(S_{a-p}, Q_{a,p}, \frac{dP}{P}\right)$$



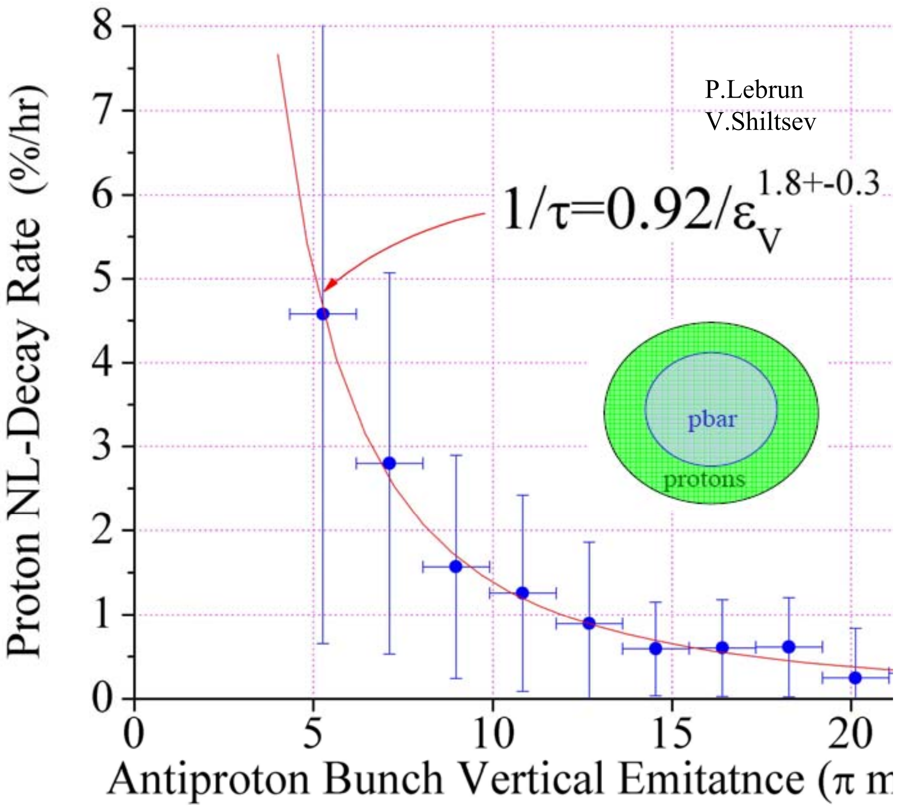


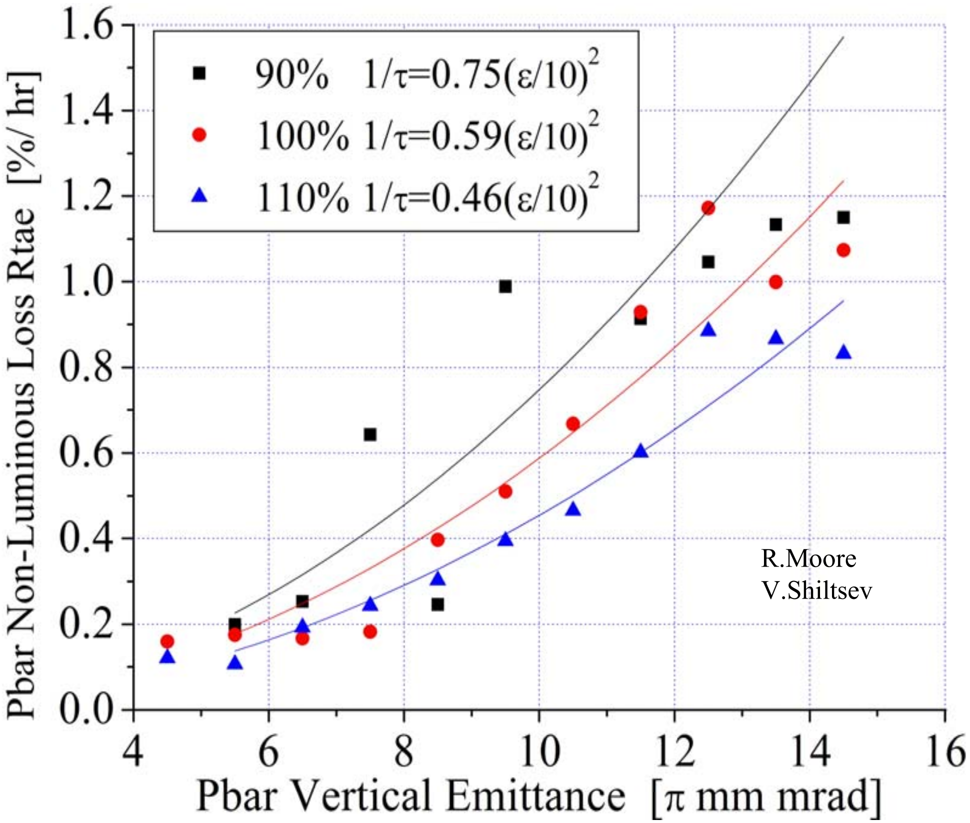




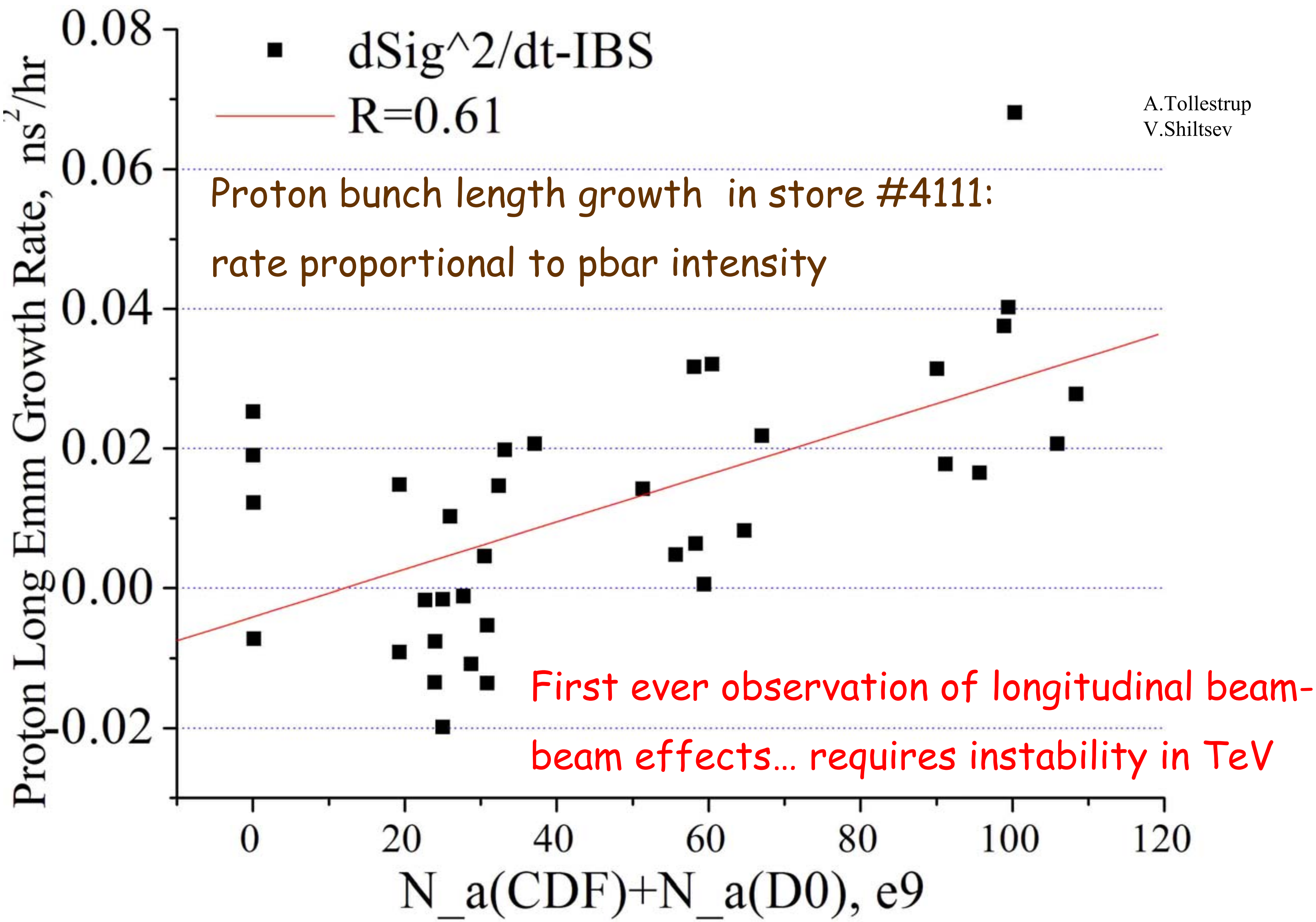
Beam Loss in Collisions

$$\frac{dN_p}{N_p dt} \propto \frac{N_a}{\varepsilon_a^2} \times F_3(Q_p, Q'_p) \qquad \frac{dN_a}{N_a dt} \propto N_p \frac{\varepsilon_a^2}{S_{a-p}^3} \times F_4(Q_a, Q'_a)$$





For Curiousity: "Alvins' Effect"

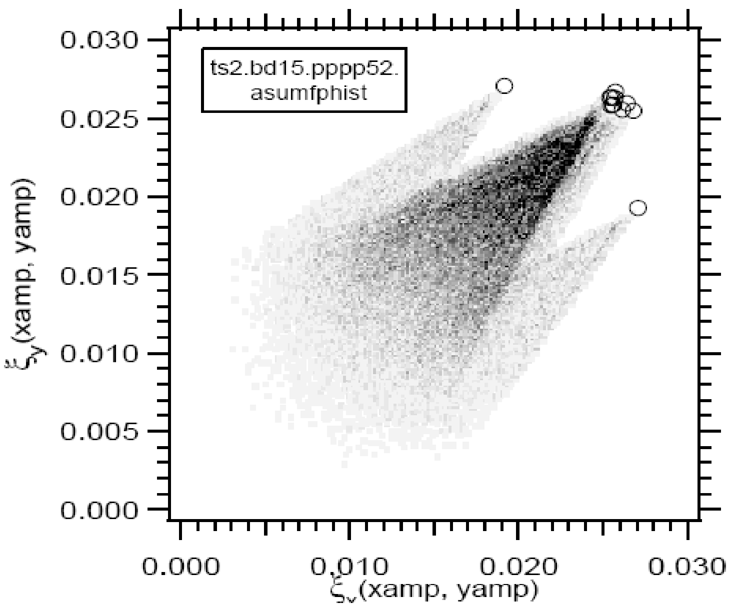


Tev Inefficiencies: Projections for FY09

	Mar-Apr'05 Now	IF RUN "AS NOW"! 3xN_a	3xN_a 1.4xEmm
P at 150	4.4% ± 2.8	13.2	13.2
A at 150	3.9% ± 2.2	3.9	7.8
P ramp	3.4% ± 0.9	8.2	8.2
A ramp	4.7% ± 1.2	4.7	8.4
P squeeze	1.0% ± 0.4	3.0	3.0
A squeeze	1.5% ± 0.5	1.5	2.0
Total before LB	*18.9% ± 3.9*	*34.5*	*42.6*
Tau_p at LB	160 hr ± 60	~60	~100
Tau_a at LB	160 hr ± 60	~160	~80
Total in Tau_L	*10% ± 5*	*~13%*	*~13%*
Total Int-L	***28% ± 7***	***44%***	***50%***

What we knew in 2001

RUN II HANDBOOK



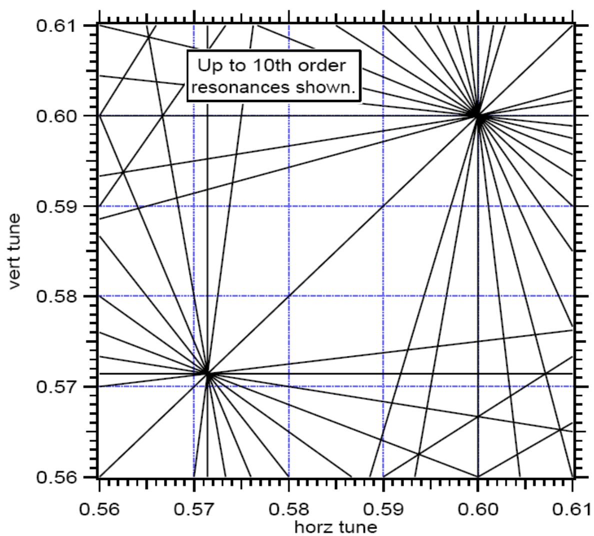
TM-1970 (1995)

Run Ib a) 6x6 → 2 head-on +10 long-range IPs
b) at 150: -7% p's -3% pbars
c) ramp-LB: -3% p's -10% pbar
d) dN_a ~ Emittance (4…14 pi)
e) shrinkage at 150 – small aperture?
f) nothing particularly bad in collisions

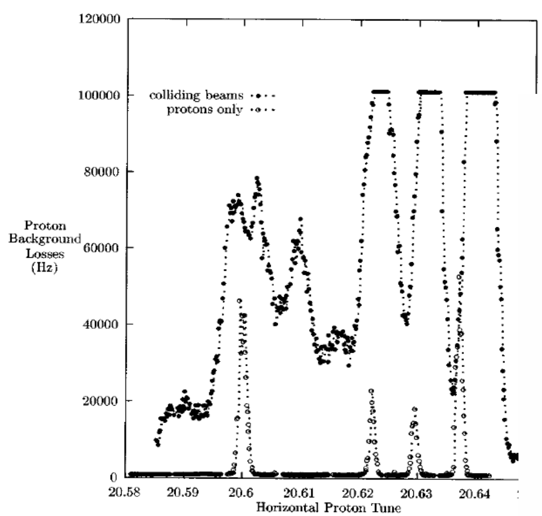
Run II: a) 36x36 → 2 HO +70 LR
b) same head-on tune shifts
c) end-of-train pbar bunches be different in collisions

$$\xi = \frac{N_p r_p}{4\pi\varepsilon_p} \approx 0.025$$

Overall = "should be tolerable…as in Run I"
… but 36xn studies in 1995 raised concerns



D. SIERGIEJ, D. FINLEY, AND W. HERR



Peter Bagley

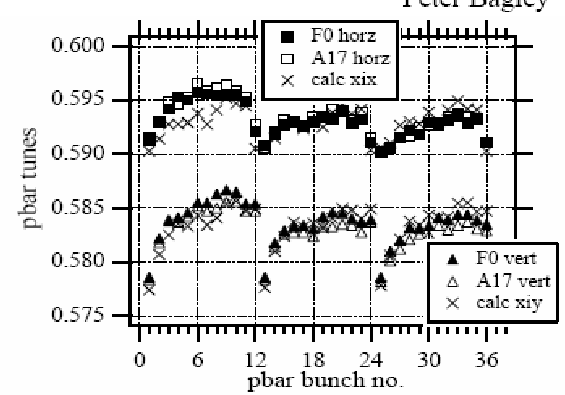
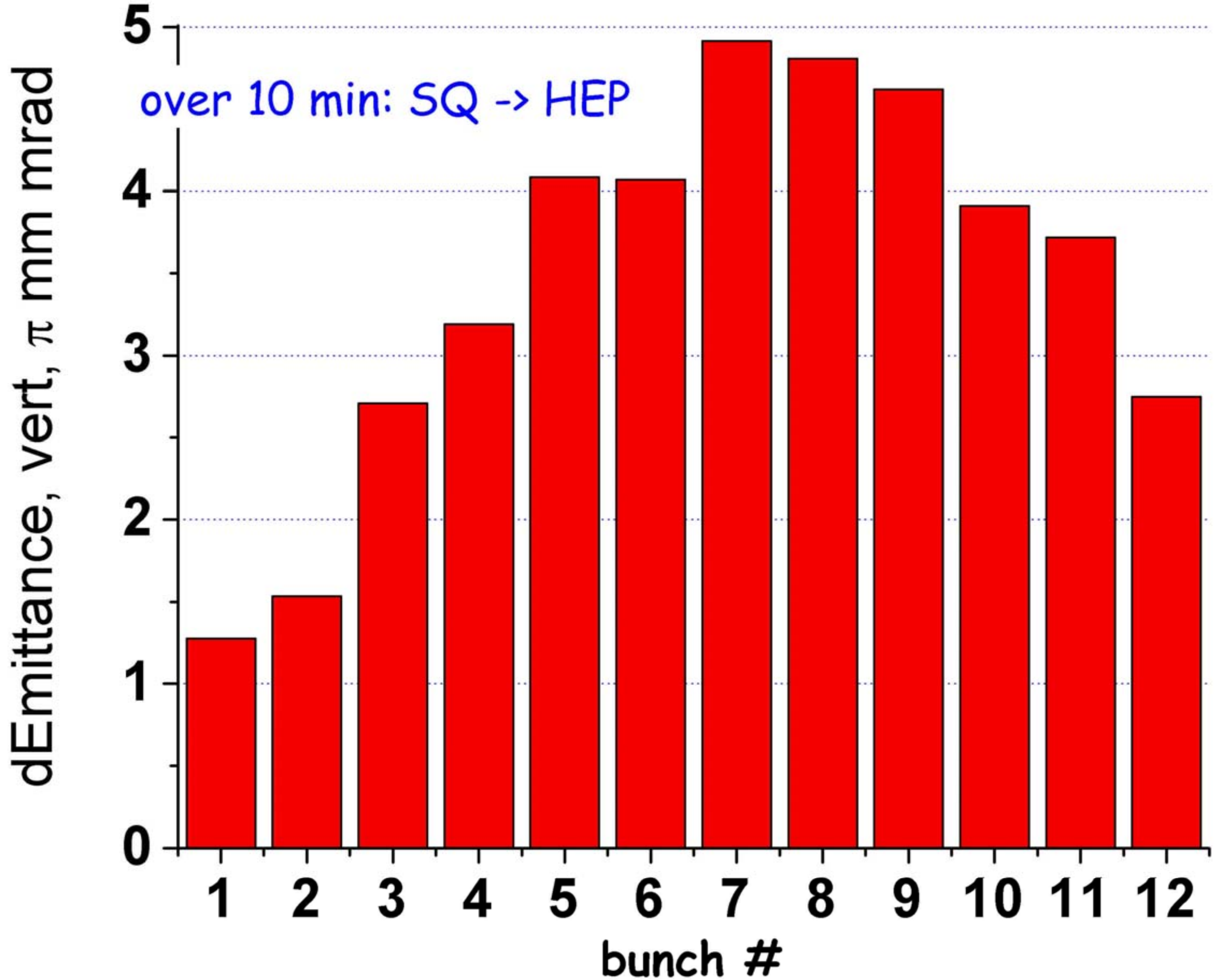
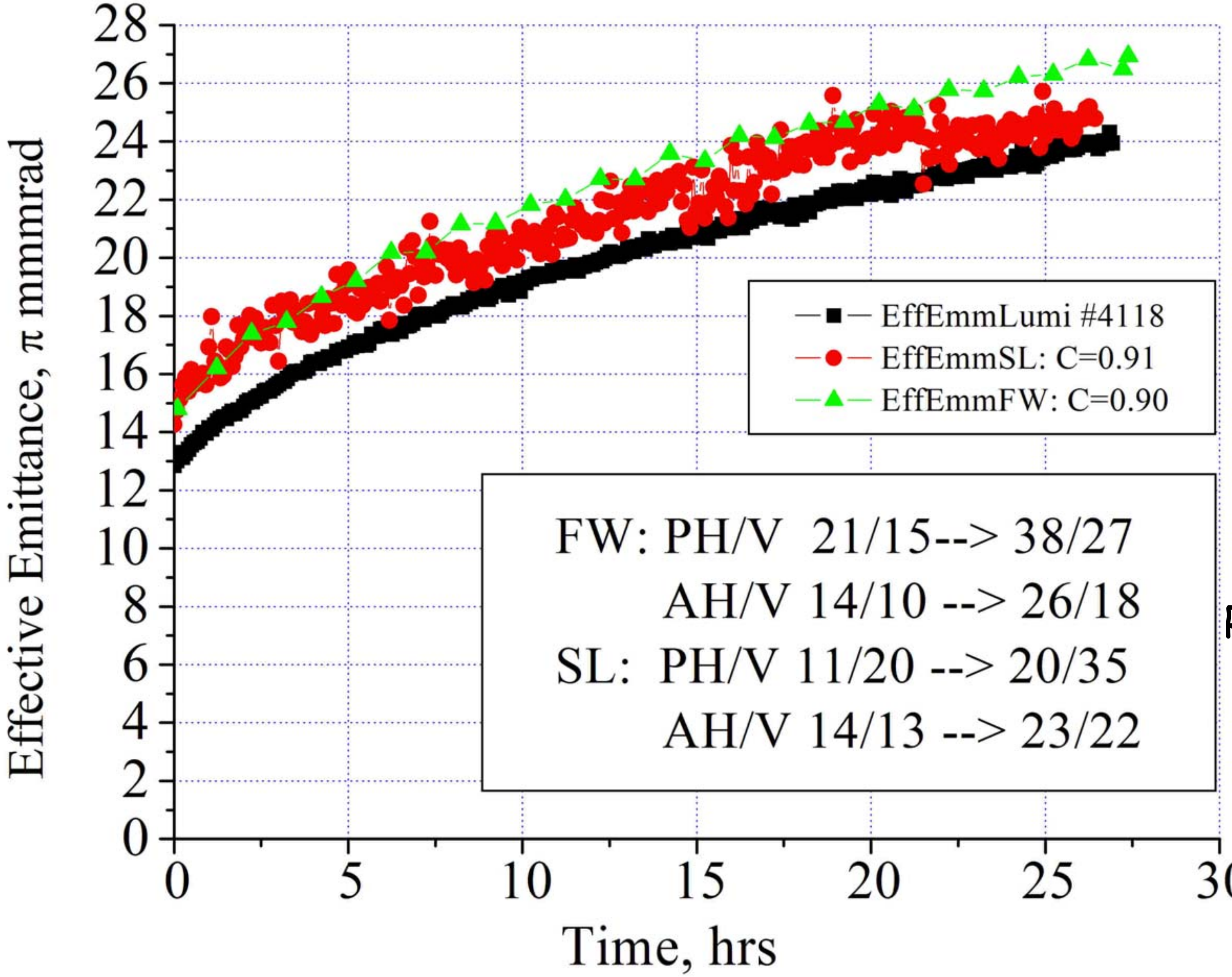


Figure 2 : Measured and Calculated Pbar Tunes for

Pbar Bunch Emittance Growth



Emittances as Seen by: B0, Sl, FWs



R~2/3

One More Piece – Needs More Thought

- PR=Proton refill:
  - every 3-5 hrs
  - remove protons at LB
  - decelerate pbars
  - inject fresh protons
  - accelerate, squeeze, scrape
  - altogether takes <30 min
  - do that 3-4 times with one pbar load
  - lose <15% of pbars (larger emm),
  - luminosity: pbar hit <-10%, proton boost +30%
  - total effect ~20% in peak, 5-10% in integral (depends on refill cycle time)